# Health and Safety
# RESEARCH
# 1975

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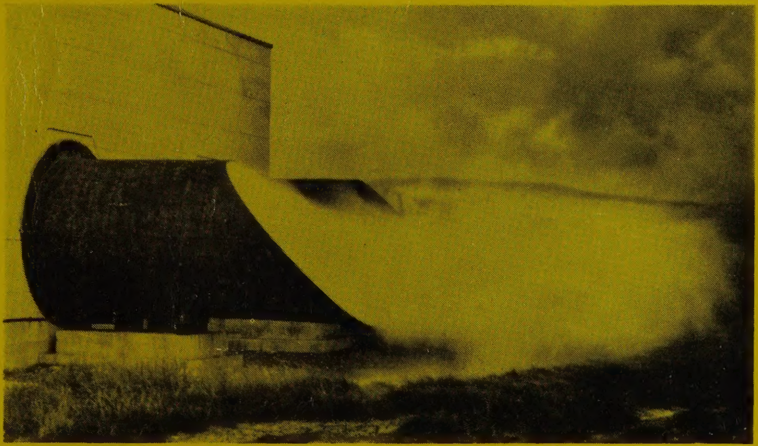

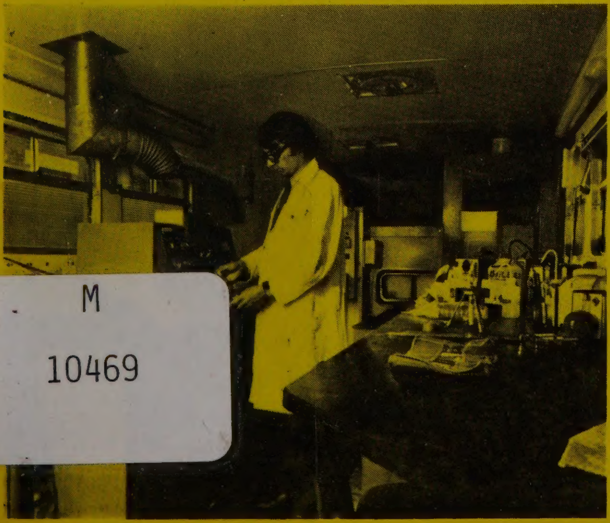

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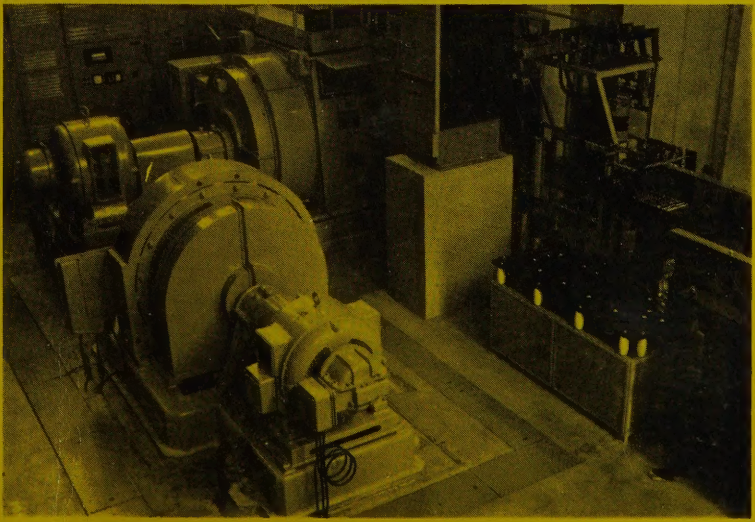

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# Health and Safety
# RESEARCH 1975

An account of the Executive's
research testing and laboratory
services incorporating
The Annual Report of the Safety in
Mines Research Establishment

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# Foreword

The Research and Laboratory Services Division (RLSD) of the Health and Safety Executive was formed shortly after the Executive came into being at the beginning of 1975. One of the urgent tasks facing RLSD was to integrate the various parts of the Executive concerned with research and development, the provision of scientific support for the Executive, and the testing of certain types of apparatus for use in industry. The activities of RLSD had also to be co-ordinated with the extramural contracts placed by Inspectorates and the Employment Medical Advisory Service.

Good progress has been made in this work but we are very conscious of the fact that much remains to be done. In particular, the coverage of our work is uneven and attention has to be paid to the task of setting up programmes that will adequately cover the needs of the industries, Inspectorates and others whom we serve. This Report is concerned with showing both the stage we have reached and giving an account of the work carried out during the year.

The first section of this Report outlines the present structure and commitments of RLSD. The main body of the Report deals with RLSD's intramural work, subject by subject. Since the Safety in Mines Research Establishment is the main research and testing establishment to be incorporated into RLSD, and since SMRE's work for the mining industry is being continued within RLSD, this part of the Report is linked very firmly to the long series of Annual Reports on mine-safety research published for the years 1921 to 1974. Near the end of the present Report there is some account of the extramural research sponsored by the Executive.

Health and safety research, and the allied fields of testing and the provision of laboratory services, are very far from being the prerogatives of RLSD, and it is fitting that I should end this Foreword by paying tribute to the many other organisations and individuals, both in this country and abroad, who are striving in ways similar to ourselves to make industry healthier and safer. We are gratefully aware of their contributions.

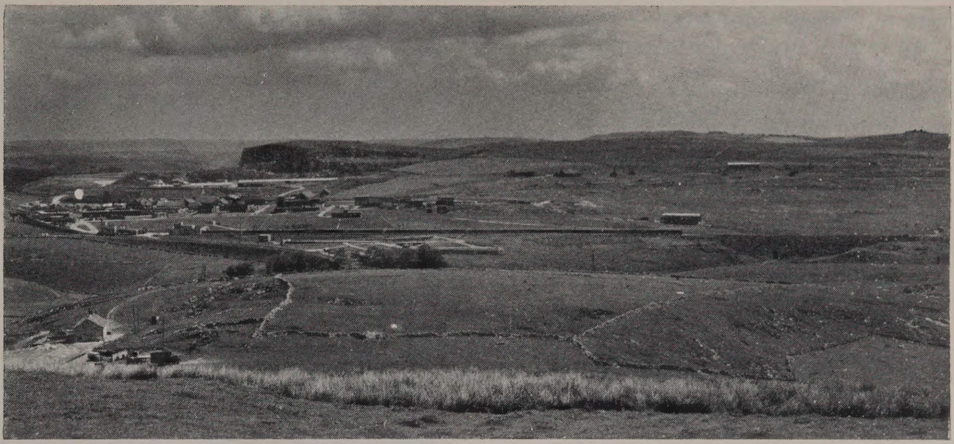
B P MULLINS
*Director, Research and Laboratory Services Division and*
*Head of the Safety in Mines Research Establishment*

**Plate 1 Buxton Laboratory**
(para 4)

1.1 General view

1.2 Part of apparatus for testing flameproof electrical equipment under full electrical loading

1.3 Gas explosion during test of mining explosive in a 1·5-m diameter gallery



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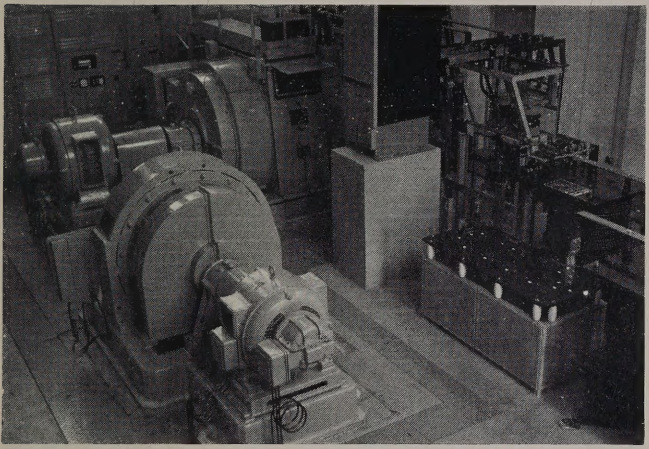

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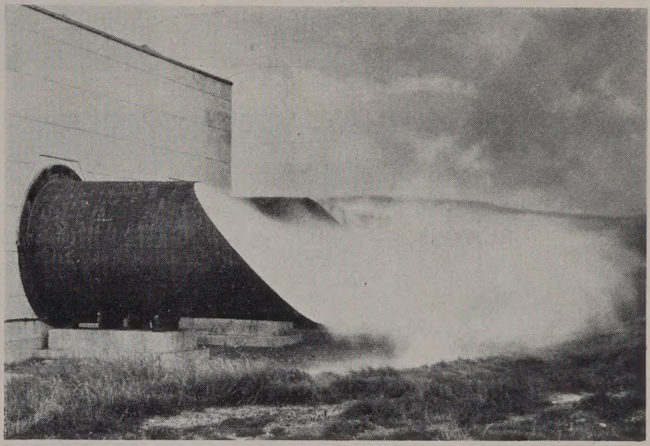

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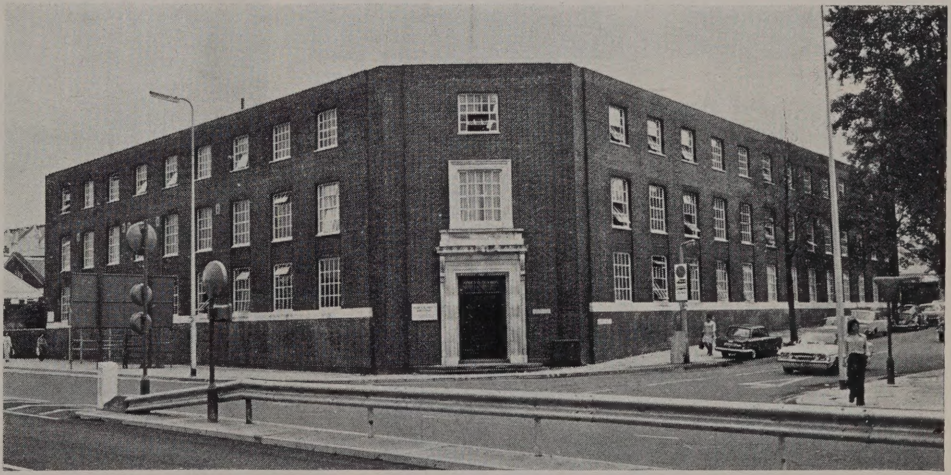
**Plate 2 Cricklewood Laboratory**
(para 4)

2.1 General view

2.2 Mobile laboratory for on site investigations

2.3 Use of mass spectrometer in search for carcinogens in samples of industrial fumes



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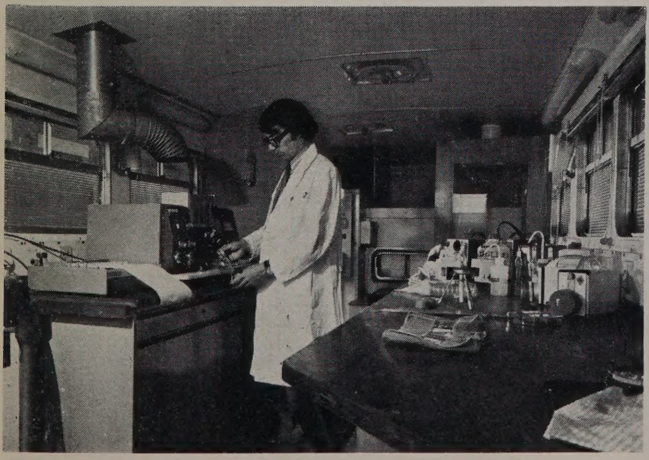

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2.3

**Plate 3 Sheffield Laboratory**
(para 4)

3.1 General view

3.2 Use of laboratory models to study ventilation problems

3.3 1000-kN senso-hydraulic machine used for studying fracture properties of low-strength structural steels

**Plate 4**

4.1 SMRE dust helmet on trial at a coke oven (para 201)
(Copyright British Steel Corporation)

4.2 Multishot exploder tester (para 108)
(Copyright Trolex Products Ltd)

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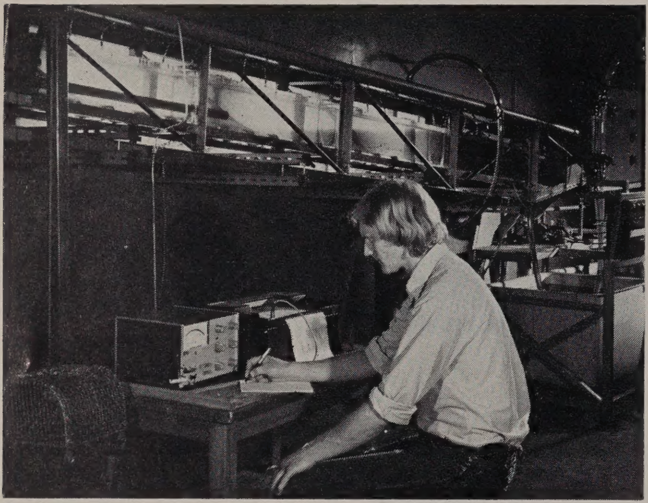

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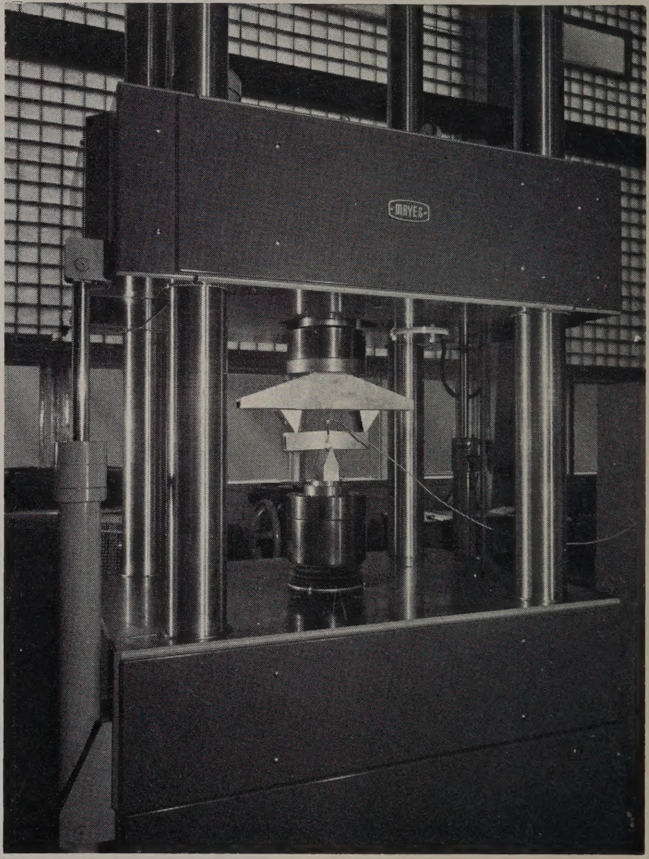

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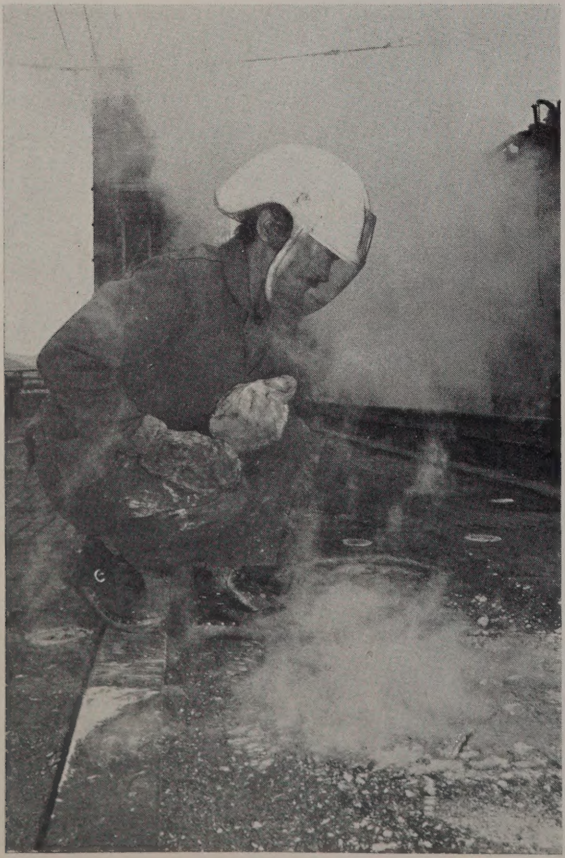

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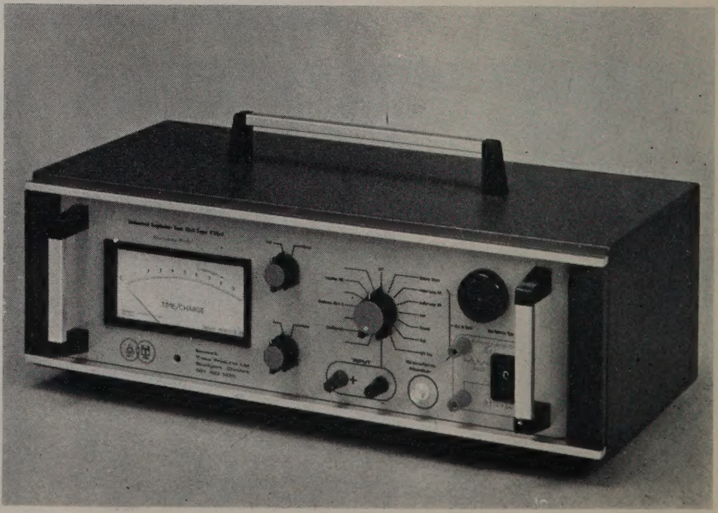

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# Structure and commitments

## Introduction

1 The research and laboratory services of the Health and Safety Executive are a combination of intramural work and work commissioned with outside organisations. The extramural work accounts for perhaps a third of our total spending on research and laboratory services. This extramural spending has the advantages that it allows access to expertise and facilities not available in the Executive, and it provides flexibility to deal with periodic fluctuations in the work load.

2 RLSD was formed by bringing together the Safety in Mines Research Establishment (SMRE), which has laboratories at Sheffield and Buxton, the Occupational Medicine and Hygiene Laboratories at Cricklewood, BASEEFA (British Approvals Service for Electrical Equipment in Flammable Atmospheres) at Buxton, and a Statistical Services Branch in London. In addition, the work and responsibilities of a group of scientists at the Royal Armament Research and Development Establishment (RARDE) are being progressively transferred from Woolwich and Potton Island to Buxton. These scientists are concerned with commercial explosives, flammable gases and liquids, and other hazardous materials (see paragraphs 148 to 168 and 231).

3 The Laboratories in RLSD have undergone some re-organisation during the year, and the laboratory activities are now organised in terms of subject matter rather than geographical location. Thus, the Director of the Buxton Laboratory has responsibilities in the areas of explosives, fires and explosions, although a small part of this work is undertaken in Sheffield. The Director of the Cricklewood Laboratory has responsibilities in the field of occupational medicine and hygiene including the work on respirable dust, respiratory apparatus, and detection of gases, that is carried out in Sheffield. The Director of the Sheffield Laboratory is responsible for mechanical engineering, metallurgy, ventilation, and accident studies.

4 Plates 1 to 3 show general views of the Laboratories and some of their facilities. The Cricklewood and Sheffield Laboratories are set in urban areas, while the Buxton Laboratory has a moorland site that can be used for large-scale experiments that could not be conducted in an urban environment.

5 There are three distinct types of scientific activity in progress within RLSD: research and development, scientific support to other parts of the Executive and the testing of equipment on a repayment basis. The Executive's extramural spending is directed towards research and development, and scientific support. Allocation of the resources for research and laboratory services is currently running at 60% to research and development, a little over 30% to scientific support, and a little under 10% to testing.

## Research and development

6 RLSD is responsible for co-ordinating the whole of the Executive's research and development programme, both intramural and extramural. Planning of research involves identifying needs, formulating and evaluating research proposals, allocating priorities, and preparing a balanced programme appropriate to the available resources.

7 The procedure for identifying needs is currently being reviewed. The field of occupational health and safety covers some six or seven broad subject areas (e.g. electrical hazards). For each area discussions throughout the relevant parts of the Executive will aim to identify needs and formulate research proposals. Views from outside the Executive will be fed into these discussions. Each research proposal will be formulated in such a way that the results will apply to as many industries as possible. Past experience suggests that relatively small increases in the scope of certain research projects will enable the projects to cover related problems in several industries.

8 The whole of the research programme is discussed by the HSE Research Committee, chaired by the Deputy Director-General. One of the main tasks of this Committee is to ensure that resources are allocated in a sensibly balanced way between the various subject areas. This is a separate consideration from the allocation of resources between industries. The current intramural programme has a strong bias towards mining problems owing to the commitments of SMRE. However, the future policy for the formulation of wider research proposals will help non-mining industries without diminishing the mining effort. During the past year there has been about a 10% increase in RLSD research staff, and all the new staff are working on problems arising outside mining. Even so, in the coming year nearly 70% of the Executive's non-mining research will be pursued through extramural contracts.

### *RLSD intramural research*

9 RLSD's intramural research is described in the main body of this Report. Much of this work is a continuation of that described in previous SMRE Annual Reports. The knowledge gained at SMRE during many years of work for the mining industry is providing a natural stepping-off place for research in other fields. For example, SMRE's pioneering work on the mixing of firedamp with the ventilating air in mine roadways has provided considerable knowledge about the mixing of gas flows of different densities. The expertise, and the techniques developed for studying phenomena on the model scale are now applicable to a wide variety of situations. One such application relates to the problems of ventilating enclosed spaces, e.g. the ventilation of a closed tank, containing a floor layer of dense gas, by

means of a jet directed from the top of the tank. The results should permit guide lines to be drawn up on ways of gaining safe access to such places. Work has recently started on another application, namely a study of the dispersion of a cloud of a toxic or flammable effluent that is different in density from the atmosphere into which it has been discharged. Special attention is being given to the problems of modelling the dispersion of such a cloud over open terrain or in the vicinity of buildings.

10 An allied study is concerned with what could be expected to happen if a flammable cloud were ignited. One project is a computer study of a Flixborough-type situation in which a large spherical vapour cloud develops just above the ground and is then ignited somewhere near its centre. The results will indicate the extent to which the explosion pressure falls away with distance from the explosion. This is an important consideration when deciding where to site chemical plants in relation to populated areas. Once the computer analysis has been completed, it will need to be checked against the results of experiments and against available data from industrial explosions.

11 Again, knowledge of coal-dust explosions can be related to dust explosions in places such as flour mills and corn silos: one project that has just been started is concerned with the explosion risks in a large silo. Measures to prevent dust explosions are not always completely effective, and so methods are needed to suppress them before they have spread far or to vent them harmlessly out of the plant. As mentioned in the body of this Report (paragraphs 182 to 186), proving tests have now been completed on the triggered water-barrier developed at SMRE for mining use. In this device, a sensor detects the flame of an advancing explosion, and sends a signal to a disperser which discharges dense sprays of water into the path of the explosion in a fraction of a second. It may be possible to use a barrier technique to safeguard a large silo.

*Extramural research sponsored by the Executive*

12 The intramural research on safety and hygiene is supplemented by extramural work. It is necessary for the Executive to establish and maintain centres of expertise within RLSD when there is a continuing demand for such expertise and when no duplication of expensive facilities is involved. However, when the demand is only a short-term one, or when expensive facilities are required that already exist elsewhere, it is a better policy to place contracts with other organisations for such projects.

13 Another reason for the extramural work is to gain additional capacity in order to cope with periodic increases in demand for the types of expertise or facilities already available in the Executive. Long-term variations in demand can be dealt with by redeploying internal staff resources, or possibly recruiting additional staff, to meet the changing situation. However, when there is a short-term peak demand in a certain area, it is often more effective to place extramural contracts.

14 The research being carried out at RARDE is in a rather different extramural category since it is being progressively transferred to the Buxton Laboratory of RLSD.

*Research into occupational medicine*

15 The Director of Medical Services is responsible for producing the Executive's research programme on occupational medicine. The research is intended to increase the value of the Executive's actions and advice by providing greater understanding of existing or new occupational health hazards. Some information on the work is given in paragraphs 280 to 285.

*Research not sponsored by the Executive*

16 Reference has already been made to intramural research and the research commissioned with outside organisations. However, there is a great deal of other health and safety research being carried out by other bodies, both in the UK and abroad. In the normal course of their work, individual HSE research workers keep in touch with the relevant parts of this research by means of scientific literature, personal visits, conferences, etc. In the mining industry, formal contact with other research organisations has also been established for many years, and there has been extensive national and international collaboration, including regular international conferences on mine-safety research. In order to aid research planning RLSD is taking steps to establish similar contacts with other industries. The research being sponsored by the European Community is an important area where a more formal contact is being pursued. Funds for this research are allocated from the European Community's budget.

17 Another issue that RLSD is examining is whether there is a need for a comprehensive register of health and safety research in the UK and, if so, what form it should take.

## Scientific support to other parts of the Executive

18 Scientific support activities are concerned mainly with helping inspectors in their day-to-day work. The activities include the routine analysis of samples taken by inspectors, calibration of equipment for field use, incident investigations and safety assessment. The demand for this support depends on operational requirements. In the event of a major incident, for example, it is often necessary to divert resources into this area from the research and development area. Over 40% of the year's spending on scientific support was extramural and, apart from some support provided

by RARDE for the Inspectors of Explosives, this extramural effort was directed almost entirely towards helping the Nuclear Installations Inspectorate.

### *Analytical services*

19 Inspectors in the field are concerned with determining whether the required hygiene standards are being maintained, or whether the degree of contamination is such that remedial action is necessary. RLSD's laboratories provide an analytical service to help inspectors and, each year, analyse thousands of samples. However, there is inevitably some delay in inspectors receiving the results of analyses carried out at Cricklewood. On-the-spot readings are a better proposition, and arrangements are being made to change the pattern of RLSD's services to put a greater emphasis on field measurements. Two field specialist groups, one in Edinburgh and the other in Manchester, will come into operation in the second half of 1976, and a third group is planned for Birmingham in 1977. Each group will operate with portable field equipment and a mobile laboratory. It is hoped in this way to deal with about 80% of the air samples in the field. The remainder will be those that need expensive and elaborate laboratory equipment, and these will continue to be analysed at the Cricklewood Laboratory.

20 The emphasis on field measurements will mean that the base laboratory at Cricklewood will no longer be mainly concerned with routine analytical services. Instead it will become increasingly concerned with the development of improved analytical techniques and equipment, both for field and laboratory use.

21 The Cricklewood Laboratory is also planning to provide a more extensive service for the calibration of the field instruments used in analytical work and also of noise meters and radiation detectors.

22 A Committee, with four working groups, has recently been set up to consider the Executive's analytical requirements. The aim is to identify needs and to decide on the best way of meeting them. The Committee includes representatives from outside the Executive so as to ensure that there is no unwanted duplication of effort.

### *Investigation of incidents and disasters*

23 Another important area of support is the investigational work to discover the causes of particular industrial accidents, e.g. explosions, fires, mechanical failures of engineering components, and so on. The investigations can involve on-site studies, simulation experiments, or the examination of samples and components in the laboratory. An account is given in paragraphs 222 to 227 of the assistance rendered by RLSD to the major investigation into the explosion at Houghton Main Colliery in which five men died.

### *Safety assessment*

24 A developing area of support provided by the Sheffield Laboratory concerns the systematic assessment of the safety of engineering systems, considering ways in which they may fail and the consequences arising from severe service conditions, deterioration with age, misuse or human error. The aim is to identify the parts that are of critical importance to safety, so that they can be given special attention during design, manufacture, maintenance, etc., and so that duplication or other techniques may be considered.

25 Current work in this area includes a major study of a modern mine winding system as part of the programme of the National Committee for Safety of Man-riding in Shafts and Unwalkable Outlets (paragraphs 241 to 245), a reliability assessment of triggered barriers for suppressing underground explosions and assessment of a variety of systems, such as commercial photo-electric devices, for the guarding of machinery (paragraphs 270 to 272). The first two of these projects are in co-operation with the Safety and Reliability Directorate, United Kingdom Atomic Energy Authority. Similar analytical techniques will be increasingly used to study possible sequences in the investigation of accidents and disasters.

### *Extramural support sponsored by the Executive*

26 The safety of any nuclear installation in the UK is the responsibility of the licensee of the site. However, the Nuclear Installations Inspectorate has the task of ensuring that the safety case is acceptable. To do this the Inspectorate has to develop its independent view without excessive reliance on data and analyses produced by the promoters of the system. Extramural work is commissioned by the Nuclear Installations Inspectorate where necessary to provide independent technical and scientific information and advice in support of their own work. Information on this extramural work is given in paragraphs 276 to 279.

## Testing, certification and approval of equipment

27 Testing services are an important part of RLSD's work. Items such as electrical equipment, mining explosives, respiratory apparatus, gas detectors, and portable lamps, are tested or assessed to ascertain their suitability for use in mining and other industries; for example, electrical equipment for use in potentially explosive atmospheres must be designed in such a way that it cannot cause a general gas ignition, and the equipment must be tested or assessed to ensure that it meets the required standards.

28 If the results are satisfactory, certificates are issued by the appropriate bodies in the Executive; for

example, BASEEFA issues certificates relating to electrical equipment for non-mining use, and Safety and General Division, Branch C, (SGD C) those relating to mining use. Certain items of equipment for use in mines are required to be of a type approved by the Executive and formal approval documents are issued by Branch SGD C.

29 An account is given in paragraph 75 of an EEC Directive relating to harmonised Standards that is being prepared by CENELEC, the European Committee for Electrotechnical Standardisation. This is an important development in the field of Standards for electrical equipment for use in potentially explosive atmospheres.

30 Tests on explosives and explosive devices for non-mining use are at present carried out at RARDE pending transfer to RLSD's Buxton Laboratory.

## Safety in Mines Research Advisory Board

31 In 1975 the Safety in Mines Research Advisory Board reported to the Health and Safety Commission, the Board's task being to keep under review and advise on the general scope, organisation and progress of research work connected with safety in mines.

32 On the 31 December 1975 SMRAB comprised:

**Members**

E C Williams CB (Chairman), *Chief Scientist, HSE*

Professor G R C Atherley, *Safety and Hygiene Group, University of Aston in Birmingham*

Professor J M Beér, *Department of Chemical Engineering and Fuel Technology, University of Sheffield*

A Bulmer, *National Union of Mineworkers*

J Carver, *HM Chief Inspector of Mines and Quarries, HSE*

Professor C F Cullis, *Department of Physical Chemistry, City University, London*

B Goddard, *Institute of Mining Engineers*

L Grainger, *Scientific Member, National Coal Board*

Professor H J King, *Department of Mining Engineering, University of Nottingham*

D H Mallinson, *Director, National Engineering Laboratory, Department of Industry*

L J Mills, *Member, National Coal Board*

Dr B P Mullins, *Director of Research and Laboratory Services and Head of the Safety in Mines Research Establishment, HSE*

A E Simpson, *General Secretary, National Association of Colliery Overmen, Deputies and Shotfirers*

**Assessors**

J D G Hammer, *HM Chief Inspector of Factories, HSE*

J A Marshall, *Head, Safety and General Division, Branch C, HSE*

**Secretaries**

Dr M Kennedy, *Principal Scientific Officer, Safety in Mines Research Establishment, Harpur Hill, Buxton, Derbyshire, SK17 9JN*

Miss B E Wall, *Principal, Safety and General Division, Branch C, HSE, Thames House North, Millbank, London SW1P 4QJ*

33 There were a number of changes in the composition of the Board during 1975. We record with deep regret the death on 28 May 1975 of Mr J W Calder, HM Chief Inspector of Mines and Quarries. His place on the Board has been filled by the new Chief Inspector of Mines and Quarries, Mr J Carver.

34 Three other new members were appointed during the year: Mr A Bulmer of the National Union of Mineworkers, who filled the place left by the late Mr K H Saunders; Mr L J Mills, a Board Member of the National Coal Board, in place of Mr N Siddall; and Dr B P Mullins, the Director of the Executive's Research and Laboratory Services and Head of SMRE, who took the place of Dr C A A Wass the former Director of SMRE. In addition, Mr E C Williams, the Executive's Chief Scientist, left the Board when he retired at the end of 1975. Mr Williams had been a Board Member since 1968 and Chairman since early in 1975.

35 Two new assessors to the Board have also been appointed: Mr J A Marshall, Head of the Executive's Safety and General Division, Branch C, in place of his predecessor Mr J R Wilson, and Mr J D G Hammer, H M Chief Inspector of Factories who took the place of his predecessor Mr B H Harvey.

36 SMRAB held three meetings during the year, two in London and one at the SMRE Buxton Laboratory. The meeting at Buxton was preceded by a visit to the laboratories in order to see work in progress.

37 The Board examined in detail the research programmes on safety in mines of NCB and SMRE, and several technical papers were presented. Particular attention was paid to work on conveyor-fire hazards arising from mechanical failure, explosion protection for the inlet and exhausts of diesel engines, climatic control in coal mines, and the use of organic plastics in flameproof enclosures.

## Detection and analysis of gases and vapours

*Polarographic methods*

38 Previous Annual Reports have described the development of oxygen-measuring instruments based on an electrochemical cell containing a metallised membrane electrode, and these instruments are now available commercially. During the year, the Yorkshire Regional Laboratory of NCB has used this type of instrument as chromatographic detectors in two separate systems involving air as carrier gas. In a gas chromatograph, the carrier gas is passed in a steady stream through a column containing a molecular-sieve material and then over a detector. Samples of the gas that is to be analysed are injected into the gas stream. The sieve material slows down the flow of the different gases in the sample to different extents, so that they arrive at the detector at different times.

39 In one of the systems, the use of air as the carrier gas means that carbon dioxide, carbon monoxide, methane, and other hydrocarbons, to which the cell does not respond, produce troughs in the oxygen signal. These troughs bear a linear relation to the concentration of the diluent gas that has produced them. Under favourable circumstances, concentrations of individual diluents can be detected down to 400 parts per million or better. Experience with this system is presently limited to laboratory applications.

40 The second system is a continuous oxygen-deficiency recorder that has been used in conjunction with a tube-bundle system at a colliery. The sieve material in the column isolates, as a mixture, the oxygen, nitrogen, and argon, from the other gases in the injected sample, and the detector compares the oxygen content of this isolated mixture directly with that of its fresh-air carrier gas. In this way it provides a figure for oxygen deficiency which is sensibly independent of temperature, pressure, contaminant hydrocarbons and zero drift and is repeatable to 0·01% oxygen. Its value to the detection of spontaneous combustion is indicated in paragraphs 174 to 177 of the present Report.

41 A description is also given in paragraphs 175 to 176 of the application of an electrochemical carbon monoxide detector and an electrochemical nitric oxide detector to the detection of open fires underground.

42 In a collaborative study with the Laboratory of the Government Chemist, a cell with a platinised membrane electrode has been shown to be suitable for recording carbon monoxide concentrations in individual puffs generated from cigarettes on a smoking machine. One problem is that the cell also responds to hydrogen, which is present in cigarette smoke. Interference from hydrogen has been reduced to an acceptable level, without unduly reducing the sensitivity to carbon monoxide, by the use of an appropriate anodic potential at which hydrogen oxidation is preferentially inhibited.

*Catalytic methods*

43 Instruments containing catalytic sensors are now in widespread use in industry for the detection and measurement of flammable gases. The majority of these instruments use the catalytic sensor developed at SMRE (Firth and others, 1972). A disadvantage of this sensor and similar ones is that they are susceptible to catalyst poisons (particularly vapours of organic compounds containing silicon or lead) found in some industrial environments. In order to overcome this problem work has been carried out on systems in which the catalyst is contained within the pores of molecular sieves. The sieve structure allows access to many important flammable gas molecules, but excludes larger molecules containing silicon or lead. Early results have shown that molecular-sieve catalysts can be several orders of magnitude more resistant to poison vapours than conventional ones.

44 Work is continuing on the catalyst system for the selective oxidation of carbon monoxide, referred to in the 1974 Annual Report (p 13). Sensors made with this catalyst have now been operating continuously for over a year, and their performance is still satisfactory.

*Semiconductor methods*

45 Reference was made in the 1973 Annual Report (p 13) to a metal-oxide gas-sensing element of the glass-bead type that was designed to measure carbon monoxide in the range 0 to 100 parts per million. Tests showed that this element had the required selectivity to carbon monoxide, but it had too long a response time to be of value in an instrument. Several other metal-oxide systems have now been tried, and an improved element having the desired sensitivity, selectivity and response time has been constructed. Present work is aimed at extending the lifetime of the new element.

*Information service*

46 RLSD provides an information service to outside organisations on the performance, availability, cost, etc. of commercially available gas-detecting instruments. The data base for this service has now been transferred to the RLSD SIGMA 6 computer. The files contain comprehensive information on over 500 instruments from about 180 manufacturers and other suppliers, and cover the detection and measurement of some 50 gases. Over 100 requests for information were processed during the year.

*Mine-air analysis*

47 During the year 2488 mine-air samples were analysed for methane content at the Sheffield Laboratory on behalf of the Mines and Quarries Inspectorate.

*Type-testing of methane indicators and gas detectors*

48 Favourable reports have been made on three methane indicators which were tested for use in the

mining industry, and on eleven out of twelve gas detectors which were tested on behalf of BASEEFA for use in industries other than mining. The detector that failed was not robust enough to meet the impact-test requirements of BASEEFA Certification Standard SFA 3007 (BASEEFA, 1972). Two of the methane indicators and one of the gas detectors were modifications to previously accepted designs, and three of the gas detectors were remote detector heads for use with gas monitoring equipment.

49 Methane indicators used by Mines Inspectors have been calibrated on sixteen occasions.

## Ventilation

*Climatic control*

50 The substitution of compressed air for electricity as the source of power for underground machinery has been considered as a possible solution to problems of excessive heat and humidity in mines (see for example Swift and Nash, 1972). Considered as a source of power alone, compressed air is too expensive to compete with electricity but the possibility has been raised that this economic disadvantage might be reversed when account is taken of the potential of compressed air as a source of cooling. The main advantage of compressed air in this context is that the useful power output of a compressed-air motor (supplied from the surface with compressed air that has been cooled to the ambient temperature) does not result in a net heat loading of the ventilation as is the case with electric motors. SMRE has carried out a study to compare the cost of a compressed-air system with the overall cost of electric power in a similar application and of the air-conditioning that would be required to produce underground air temperature conditions such as would exist if the machinery were powered by compressed air. (Consideration is currently being given to the introduction of air conditioning into some British mines.)

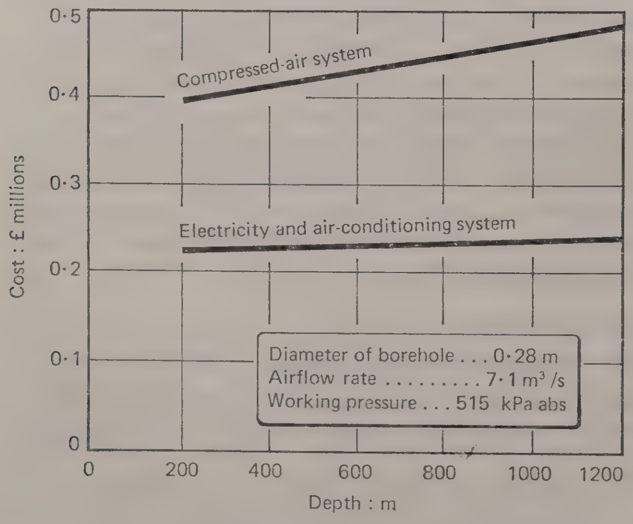
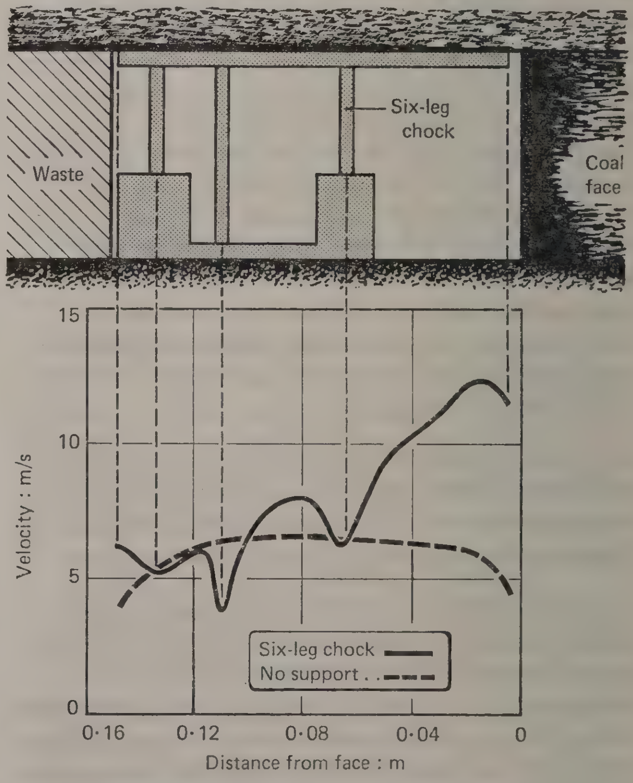


**Fig 1** Costs of alternative systems as functions of depth.

51 Each power source was costed for a set of conditions reasonably typical of a British mine, namely a district 5 km from the shaft which had to be supplied with 750 kW of power.

52 A preliminary study was made to compare the cost of supplying compressed air direct to the district down a specially drilled borehole with the cost of a supply via the downcast shaft and along an underground distribution main. The study was concerned with depths down to 1200 m and, within this range, the borehole supply was found to be more economic, mainly because a borehole would reduce pressure loss



Measurement at mid height of face, and on line at right angles to face and midway between adjoining chocks.

**Fig 2** Model experiments on effects of roof supports on ventilation flowing parallel to face.

and hence running costs. In the main investigation, therefore, it was assumed that compressed air would be supplied via a borehole. The diameter of the borehole was fixed at its optimum size, i.e. the size that would minimise the combination of the original capital cost of the system and the running costs incurred in providing the necessary power over a specified number of years at a specified rate of interest. Figures of 10 years' running time and 10% interest, which were selected as being reasonably typical, gave an optimum borehole diameter of 0·28 m.

53 Figure 1 shows the cost of each power system as a function of the depth of the district supplied. In the general case considered, the compressed-air system is markedly more expensive than the electrical system, even though the cost of the latter includes air cooling. Thus compressed air cannot be considered as a reasonable economic alternative to electricity as a power source unless other factors such as a reduction in the dust contamination of the intake air due to the lower velocities, and a reduction in the pickup of heat and moisture from the strata, can be realised and are important in a particular case.

*Airflow along faces*

54 SMRE has been investigating the possibility that gas released at the face of a supported seam is held near the face by the 'wall' formed parallel to the face by the roof supports. A one-twentieth scale model of a coal face was used in the experiments; gas was released from a vertical line source at the face, and the velocity and concentration of the gas were measured along and at right angles to the face. Measurements were made without props, with simple props, and with six-leg rigid-base chocks.

55 Figure 2 shows airflow velocity profiles taken at right angles to the face, both in the absence of supports and with a row of six-leg chocks. With the chocks, the airflow velocity is low in the planes of the chock legs, and highest near the face. This high velocity produces good mixing in the face region which, together with the overall velocity increase caused by the blockage of the props, can be expected to reduce the concentration of gas in this region so that the support 'wall' does not result in unduly high concentrations near the face. Preliminary examination of concentration profiles tend to confirm this view.

# Frictional heating

*Ignition by impact*

56 Previous work on the kinetics of impact in drop-weight experiments (Powell and Quince, 1972) has shown that friction during impact plays an important part in making surfaces hot enough to ignite flammable gases and that, assuming a knowledge of the physical properties of two bodies undergoing impact, it is possible to forecast the heat energy dissipated at the surfaces in contact and the resulting surface temperature. Further work is being undertaken with a range of metals to verify the theoretical description.

57 The apparatus used consists of a copper beryllium target plate inclined at angles between 25° and 80° to the horizontal and a cylindrical weight to which metal disks may be attached. The weight is allowed to fall and strike the target plate. The path of the weight is shown in fig 3 superimposed on the photographic trace produced by light reflected from mirrors attached to the weight. The record of the trace is used to determine the velocity before impact and the velocities of translation and rotation after impact. The rise in temperature of the impacting surfaces is measured from their thermoelectric emf displayed on an oscilloscope. Copper beryllium was chosen for the target plate because of its hardness and because it produces an easily measurable thermoelectric output when used in conjunction with various metals and alloys. So far

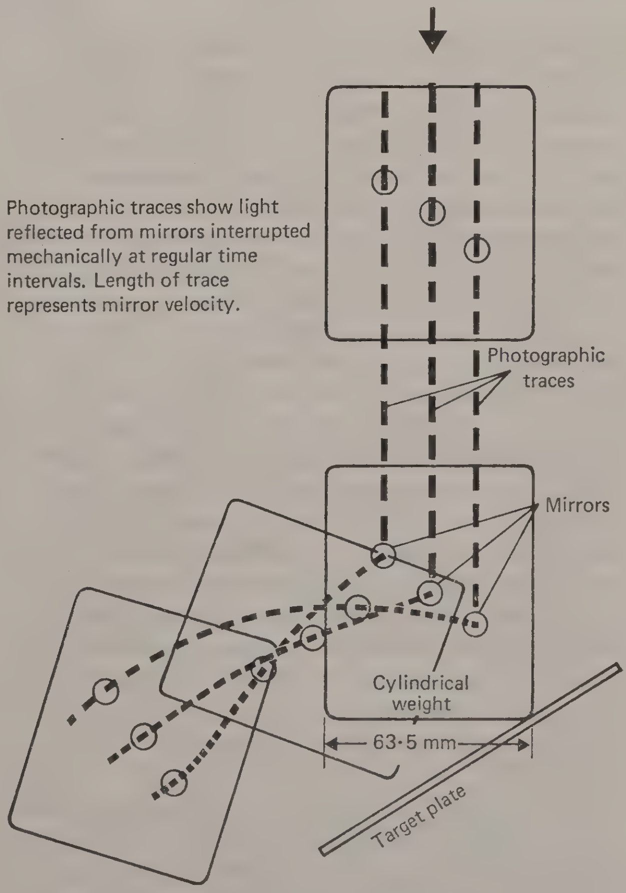

Photographic traces show light reflected from mirrors interrupted mechanically at regular time intervals. Length of trace represents mirror velocity.
Photographic traces
Mirrors
Cylindrical weight
63·5 mm
Target plate

**Fig 3** Path of cylindrical weight before and after impact on target plate.

three alloys of aluminium have been used and it is now planned to examine nickel alloys.

58 The experiments so far have verified the theoretical prediction that the harder alloys produce higher temperatures under given conditions.

### *Ignition by rapidly heated metal strips to simulate frictional impact*

59 Recent Annual Reports have described a study of the ignition of methane-air mixtures by strips of tungsten foil which were rapidly heated by capacitor discharge. The aim of this work is to simulate the surface heating conditions produced by impact and to discover the effects on the probability of ignition of changes in surface area, gas concentration, peak temperature and the rate of rise and fall of temperature.

60 The most difficult part of this work is the temperature measurement. The temperature rises and falls so rapidly that the necessary measurements cannot be made with commercially available devices. Much of the recent work has therefore been concerned with developing a satisfactory temperature measuring system.

61 Such rapid changes in temperature can only be measured by using a radiation pyrometer. However, a total-radiation pyrometer cannot be used since it is necessary to know the emissivity of the hot surfaces and this is constantly changing due to oxidation: two-colour pyrometry must therefore be used. The laboratory pyrometer used in work reported in previous Annual Reports had the disadvantages that inaccuracies could result from relative movement between the components and that the instrument was difficult to focus onto the surface under investigation. A semi-portable instrument has now been built which overcomes these difficulties. The components of the pyrometer are rigidly housed within the modified body of a single-lens reflex camera and the focusing system of the camera is used to direct the instrument accurately onto the heated surface. The radiation from the heated surface is split into two beams which pass through optical filters onto two photosensitive devices. The two outputs are fed into a storage oscilloscope and the ratio of the intensities of the two filtered beams gives a measure of the brightness temperature of the surface irrespective of the emissivity.

62 The work has now reached a stage where temperatures between about 600°C and 2000°C can be recorded with an accuracy of ±30°C in conditions where the change from ambient to peak temperature takes as little as one millisecond.

### *Ignition hazard from light alloys*

63 A sample of self adhesive reflective material used for notices and said to contain aluminium was tested for thermite reaction with rust.
64 In a series of impact tests no such reaction was observed.

### *Ignition hazard from steel*

65 For work on the ignition hazard of an auxiliary mine ventilation fan, in which the impeller was allowed to rub on the structural casing, see paragraphs 225 to 227.

### *Ignition caused by machine picks*

66 Previous SMRE investigations into the effect of water on suppressing methane-air ignitions during rock cutting were conducted with a single pick, and showed that water applied behind the pick is significantly more effective in suppressing ignition than water applied to the front of the pick such as the water jet used in pick-face flushing to suppress dust.

67 A large-scale rock-cutting machine has now been modified so that experiments can be carried out to determine what effect the pick-face flushing of one pick has on suppressing ignition caused by friction from the preceding pick. The machine has been fitted with two radial-type coal cutter picks and it is possible to vary the vertical and horizontal separation between them by up to 300 mm. Figure 4 shows one of the experimental arrangements. The water jet is placed as for dust suppression of the second pick, but the tip of the second pick has been removed so that it runs clear of the rock and the only frictional heating is that caused by the cutting action of the first pick.

68 The preliminary results suggest that a water jet directed at the front of one pick has little, if any, effect on suppressing ignition caused by a pick 150 mm in front of it.

### *Mineral cutting and fracturing by high-pressure water jets*

69 The 1974 Annual Report (p 23) referred to a cutting technique intended to combine pulsed water jets and a conventional coal plough. The technique has now been tried at an opencast coal site at Ilkeston.

70 The tests were made in a 1-m thick seam of medium strength coal. The nozzle assembly on the transportable high-pressure water jet rig (1973 Annual Report, p 23) was replaced with a plough blade with a jet outlet passing through it. The technique depends on

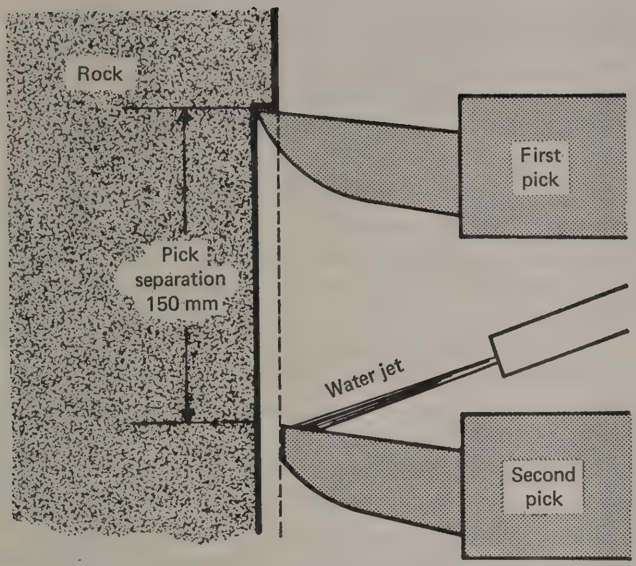


**Fig 4** Position of picks and water jet during rock-cutting experiments.

the ability of the jet to weaken the coal immediately ahead of the blade. It was hoped that this would enable a web of coal up to four times the normal thickness to be cut without increasing the haulage forces required. Conventional coal ploughs usually cut a web up to 80 mm thick, with haulage forces of up to 150 kN.

71 In the small number of tests conducted the plough blade and jet assembly were pushed through the exposed face of the coal seam by hydraulic rams to cut webs up to 300 mm thick. The forces required were between 6 and 21 kN. Jet pressures in excess of 300 MPa seemed to be the most effective in these tests. In a few instances the specific energy of the coal-getting process, i.e. the work done in removing unit volume of material, was very low, being between 1 and 5 MJ/m$^3$, which is similar to values obtained for the conventional coal plough used underground.

72 However, these results cannot be compared directly with the forces required by a conventional plough since it was not possible to reproduce the loading conditions that might be expected underground, because the overburden to the seam used in the tests had to be stripped back so that it would not fall on the equipment. The results obtained from the tests are therefore inconclusive as regards the efficiency of the system, but they do show that the technique is feasible.

# Electrical equipment

## Certification and testing standards

73 Electrical equipment for use in flammable atmospheres in mines is certified by the Executive's Safety and General Division, Branch C. This certification is based on the results of tests or assessments carried out by RLSD to the appropriate British Standards. During 1975 a total of 195 certificates and supplementary certificates were issued.

74 Certificates for equipment for use in flammable atmospheres in industries other than mining are issued by BASEEFA (British Approvals Service for Electrical Equipment in Flammable Atmospheres). Equipment is certified to both British Standards and BASEEFA Certification Standards. The certificates are based on tests or assessments conducted by RLSD and other testing authorities and on technical assessments made by BASEEFA, and cover the established methods of protection of electrical apparatus designed for use in flammable atmospheres, including apparatus designed solely for use in Zone 2 (sometimes known as Division 2) areas of hazard. During 1975 a total of 426 certificates and supplementary certificates were issued including Schedules to equipment previously certified by H M Chief Inspector of Factories. There was a noticeable increase in the demand for certification from overseas, particularly from Europe and USA.

75 There has been an important development during the year in the field of standards for electrical equipment for use in potentially explosive atmospheres. In December an EEC Directive concerned with electrical equipment, other than underground mining equipment and medical equipment, was issued which relates to harmonised standards. It is intended that standards

being prepared by CENELEC, the European Committee for Electrotechnical Standardisation, will form these harmonised standards which will be used by member countries of EEC and by other countries represented on CENELEC. The standards will affect export: when the Directive is implemented they will become the national standards of the countries concerned, and it is intended that any equipment that satisfies these standards shall not be refused entry to, or use within, member countries of EEC.

76 BASEEFA and Safety and General Division, Branch C, have been nominated as bodies approved by the United Kingdom for the issuing of the certificates of conformity and inspection certificates referred to in the Directive.

77 RLSD staff have attended meetings of CENELEC and of the British Standards Institution for the purpose of drafting the standards.

## Intrinsically safe equipment

*Piezoelectric ceramic devices*

78 RLSD has investigated the possible hazards associated with the use of piezoelectric ceramic devices as components in intrinsically-safe circuits; such devices are being used with increasing frequency in, for example, microphones and acoustic warning devices. The important feature of a piezoelectric transducer is that when deformed it generates charge which appears as a voltage if the transducer is open-circuited, or as a current if short-circuited. The deformation of the transducer may be caused by a mechanical force or by a temperature change. The generation of open-circuit voltages presents the main hazard as far as gas ignition is concerned. Several thousand volts can be generated at readily attainable levels of mechanical stress, or by temperature changes of a few dozen degrees Celsius; and the capacitance of the devices is such that incendive breakdown sparks are easily obtained with virtually all commercially available transducers. This means that some method for avoiding the generation of high voltages under practical conditions must be provided. There are a number of ways in which that can be done. Such devices can usually be protected against mechanical stress by guarding or by enclosure, or the maximum voltage can be limited by means of shunt devices, e.g. zener diodes. To provide protection against the effects of temperature change a shunt resistor (R) can be used provided the time constant (R × device capacitance) is small compared with that associated with the temperature change.

*Current-limiting resistors*

79 For many years, only wire-wound resistors were accepted for current-limiting purposes in intrinsically safe equipment because it was considered virtually certain that they would fail in a safe manner, i.e. to an open circuit. More recently, metal-oxide and metal-film resistors using ceramic substrates have been accepted as an alternative to wire-wound resistors. However, carbon-film resistors have not been accepted because failure to a low-resistance condition was a problem with early forms of construction, and because some life-test information suggested that certain types failed to a low-resistance condition when their power rating was exceeded.

80 Recent life tests have shown that carbon-film resistors on a ceramic substrate increase in resistance and finally fail to an open circuit condition when subjected to substantial power overloads. However, if such a resistor is encapsulated, the failure is to a low-resistance state. The same mode of failure has been observed with metal-oxide and metal-film resistors, and appears to result from carbonisation of the coating that is applied to the conducting layer of the resistor to provide protection from moisture. Carbonisation takes place under conditions where overheating occurs and there is insufficient oxygen available to convert the carbon in the coating to carbon dioxide. When vitreous enamelled wire-wound resistors were similarly tested, there was no evidence of a carbonised coating.

81 In practice, current-limiting resistors must not be subjected to more than two-thirds of their power rating (BASEEFA, 1972a). In tests carried out at RLSD there was no deterioration of encapsulated film-type resistors when they were subjected to two or three times the manufacturer's power rating for a period of over six months. On this evidence it appears that properly rated film-type resistors, whether encapsulated or not, are as acceptable as wire-wound resistors for current-limiting purposes.

*Type-testing of intrinsically safe electrical equipment*

82 During the year electrical equipment for use in the mining industry was assessed at RLSD with a view to certification by the Executive within the terms of BS 1259 (British Standards Institution, 1958) and electrical equipment for use in other industries was assessed on behalf of BASEEFA (British Approvals Service for Electrical Equipment for Flammable Atmospheres) with a view to certification within the terms of BASEEFA Certification Standard SFA 3012 (BASEEFA 1972a).

83 One hundred and fifty systems were considered for certification: all received favourable reports, though in some cases only after modifications had been made. The range of equipment tested was very wide, with the accent being on environmental-monitoring systems.

84 Sixty-three of the systems examined were assessed for compliance with BS 1259 and eighty-three for

compliance with SFA 3012. The remaining four items were environmental-monitoring systems which were accepted for use underground under the terms of letters of no objection or of experimental approval.

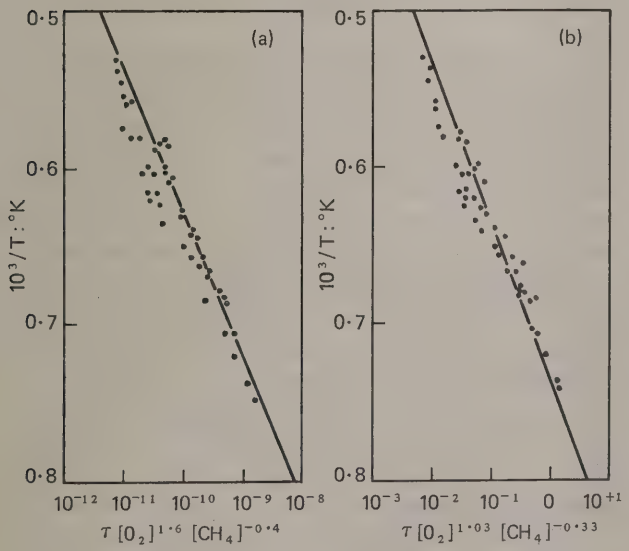
85 In addition, sixteen minor variations to previously certified equipment were considered and accepted by letter.

86 The total number of systems examined represents a marked increase over the past few years; the only time this number was surpassed was in 1962 when 161 systems were considered.

## Flameproof equipment

*Maximum experimental safe gap* (MESG)

87 The 1974 Annual Report (p 26) referred to a computer program that was developed to follow the progress of chemical reaction of a static flammable mixture. Some experimental results for the ignition of methane–oxygen–argon mixtures in a shock tube have now been compared with corresponding results generated by the computer program. The two groups of workers who obtained the experimental results (Seery and Bowman, 1970; Liftshitz and others, 1971) fitted lines to their data. These lines are shown in fig 5; the function of pre-ignition time and initial oxygen and methane concentrations are those that these workers found to give the best fit to their experimental results. The points shown on the figures are the results of RLSD computer 'experiments' covering a wide range of initial temperatures, pressures and mixture composition. As can be seen, the experimental and computer results agree fairly well. The computer results are from the same series of computer experiments, but use different definitions for the end of the pre-ignition period corresponding to those used by the two groups of workers; as mentioned in the 1974 Annual Report (p 26), one object of the work is to define the end of the pre-ignition period in an MESG experiment.



$\tau$ = pre-ignition time : s [ ] = initial concentration : mol/ml

Lines show experimental results from (a) Seery and Bowman (1970)
(b) Lifshitz and others (1971)

Dots show results of SMRE computer 'experiments'

**Fig 5** Ignition in methane–oxygen–argon mixtures in shock tubes.

*Hazards from the volatilisation of insulating materials in flameproof equipment*

88 Work described in previous Annual Reports on problems associated with electrical arcing across the surface of organic plastic insulating materials in flameproof enclosures has now been concluded. It must be emphasised that all these materials, if they are subjected to a severe electrical fault, which causes surface tracking or arcing, are capable of producing sufficient flammable gas to burst a flameproof enclosure or to create an ignition or a fire hazard outside the enclosure.

89 They can, however, be divided into three groups, according to their suitability for use as insulators. With the first group of materials, an arc initiated under our standard test conditions (1972 Annual Report, p 30) would self-extinguish. These materials, which include certain types of glass reinforced polyester-bonded 'dough moulding compounds', are the most suitable for use as insulators. The second group contains materials (e.g. urea-formaldehyde) that, while they allow the test arc to burn for the duration of the applied voltage, do not cause it to restrike after the current has been momentarily switched off. The third group contains almost all the phenolic materials and these cause the arc to restrike after the current has been momentarily switched off. The materials in this last group should be avoided for insulating purposes in flameproof enclosures whenever possible, and especially if subject to electrical stress at high prospective fault levels.

90 The results of this programme of research have been published (Lord and Barbero, 1975).

91 Work on the development of a bi-stable temperature-sensitive device that can detect a short-circuit arc in a flameproof enclosure and make or break an electric circuit in less than two seconds was described in last year's Annual Report (p 28). Tests on the device have been completed, with satisfactory results, and it is now being examined by NCB.

92 The apparatus used for the plastics experiments and the low power level of the arc, together with the

distance of the arc from the flanges, precluded the possibility of ignition of the expelled gas, or of an external mixture, by arc plasma. The 1973 Annual Report (p 26) described how the expelled gases, which contain about 30% hydrogen, were ignited outside the enclosures by particles of molten electrode material entrained in the gas stream. There is no record of these particles ever igniting an external methane–air mixture. However, such a mixture can be ignited by arcing alone, if the arc is within a certain distance of the flange gap. Ignition is thought to be by expelled arc plasma and to verify this theory comparative experiments are being carried out with two sources of arc plasma one of which produces no particles. This source is a 'plasma gun' which produces a jet of plasma from a capacitor discharge between hard metal electrodes. The other source is a normal arc struck between two copper electrodes and triggered by the fusion of a fine wire which initially short-circuits the electrodes. In the experiments with the copper electrodes, a consistent relationship is emerging between ignition probability for various flange gap widths, distances of the arc from the gap, arc current, and arc duration.

### *Short-circuit testing*

93 The short-circuit test facility at the Buxton laboratories has been made available to a company developing two new circuit-breakers. Several other organisations have expressed interest in the use of this independent facility for development work on new types of switchgear.

### *Type-testing of flameproof equipment*

94 During the period, sixty-one units were received for examination and test prior to certification, two for compliance with BS 229 (British Standards Institution, 1957) and the remainder for compliance with BS 4683: Part 2 (British Standards Institution, 1971b). Fourteen of these units were intended for use in coal mining only, forty-three for use in other industries, and four for use in both coal mining and other industries. In addition, seventeen units were received with a view to certification, on the basis of examination only, for compliance with BS 4683: Part 2, and a further three units for certification to the same standard on the basis of examination and static pressure test only.

95 Eight of the units submitted for testing failed. Five of these were re-submitted after modification by the manufacturers and were then found to be satisfactory. Of the units received for examination only, four failed to meet the requirements; all four were satisfactory when re-submitted after modification. In addition, six units which had failed parts of their tests during 1974 were re-submitted after modification; all were found to be satisfactory.

96 BS 4683: Part 2 allows units to be declared exempt from routine pressure testing during manufacture provided that a specimen has withstood a hydraulic pressure test of four times the maximum smoothed pressure obtained from explosion testing. At the request of the manufacturers, nineteen units were submitted to these hydraulic pressures. Five of the units failed but one of these passed when it was re-submitted after modification.

97 One hundred and thirty-three supplementary certificates were granted after RLSD had examined drawings and, in most cases, equipment. Minor variations to nineteen flameproof items were considered and accepted by letter.

98 Investigations have been undertaken to assess the suitability of a dynamic method of pressure testing which an applicant wished to use as an alternative to the normal static method of BS 4683: Part 2. A portable instrumentation system was developed at RLSD to measure gas explosion pressures and used at the applicant's works to check his equipment. The results were satisfactory and the method has been recommended to the Executive's Safety and General Group, Branch C, the Certifying Authority responsible for Group I equipment.

99 One unusual item was a range of cable glands which were tested for compliance with Type Y (direct entry) connections specified in BS 4683 Part 2. The glands included a flame barrier made from an epoxy-based putty-like hard-setting compound. The results of the tests were such that BASEEFA were able to accept the glands for use with Group II equipment.

100 Another unusual item was a foam-metal disk used as both flame arrestor and sound vent on a high-powered loud-speaker. Apart from the disk the unit complied with normal flameproof requirements. The first disk tested was unsatisfactory and the production techniques were examined to see whether disks with a satisfactory pore structure could be produced consistently. Subsequently, satisfactory disks were produced and BASEEFA were advised to accept the device subject to certain safeguards being applied in the manufacture of the disks.

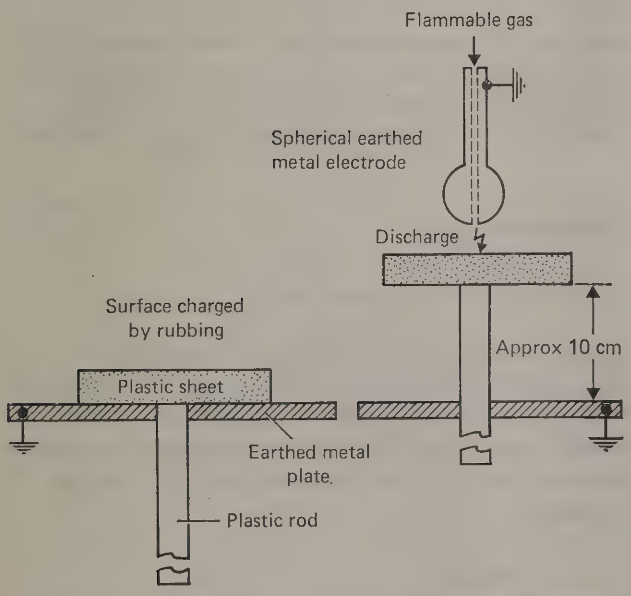
## **Other equipment**

### *Electrostatic hazards of small plastic surfaces*

101 It is well known that the risk of igniting gas by discharges of static electricity can be reduced by using materials with 'anti-static' properties, which do not accumulate dangerously high levels of charge. In draft international standards for electrical equipment for use in hazardous atmospheres, requirements are laid down

to ensure that equipment enclosures are safe in this respect.

102 Equipment that does not exceed certain minimum dimensions is exempted from the requirements for the use of anti-static materials. The minimum dimensions proposed are based largely on the work of Heidelberg (1968) who studied discharges from plastic sheets which were charged by 'spraying' them with a corona discharge. RLSD has studied discharges from plastic sheets up to 5 mm thick, one surface being charged by rubbing with a suitable material (e.g. a paper tissue) while the opposite surface was in contact with an earthed metal plate (fig 6a). The charged sheet was then raised some 10 cm above the earthed plate and a discharge was produced by bringing a spherical earthed metal electrode, at the end of a rod, to the charged surface. A small hole was bored down the rod and through the electrode so that a flammable gas mixture, passed through the hole, could be provided in the region of the discharge without the need for an explosion chamber (fig 6b). It was found that methane–air mixtures could be ignited by discharges from surfaces down to 100 cm², and hydrogen–air mixtures by discharges from surfaces down to 5 cm² in area. This latter figure is substantially below Heidelberg's published figures (1968) but he informs us that he has subsequently obtained figures closer to ours. Experiments were also carried out with hand-held plastic tubes and rods, which were also charged by rubbing and discharged to an earthed metal ball. Ignitions of hydrogen–air mixtures could be obtained from tubes and rods down to 9 mm in diameter.



(a) Charging plastic sheet

(b) Electric discharge between charged plastic sheet and electrode

**Fig 6** Gas ignition by discharge of static electricity from a plastic sheet.

*Hazards associated with high-voltage apparatus*

103 Nine electrostatic paint-spray and powder-spray guns have been submitted for certification in conformity with BASEEFA Certification Standard SFA 3010: Part 1: 1974. None of the guns examined during 1975 fully met the requirements of the standard, and alterations to ensure compliance have been recommended. In several cases major modifications were required. Some of the guns tested incorporate novel means for charge generation and current limitation and this has led in some cases to problems in determining the factors influencing safety.

104 Tests have been carried out on a liquid-filled extra-high-tension cable in order to determine the maximum safe voltage at which it could be used. Tests were devised to examine the incendivity of discharges produced from the cable both in normal operation and also when the cable was punctured.

105 Some further studies have been made of the parameters that affect the incendivity of discharges from the surface of an insulator surrounding a high-voltage conductor. The effects of varying the insulation thickness and permittivity have been investigated. Work continues in this field.

*Properties of insulation materials*

106 The properties of insulation materials are important when considering the safety of electrical equipment intended for use in flammable atmospheres since, in many cases, failure of insulation can lead to dangerous conditions. At the request of BASEEFA we are examining standard methods of assessing some physical properties of insulating components used to encapsulate or coat electrical and electronic components.

107 Work on the tracking properties of electrical insulating materials is continuing. A high-voltage (1·0 to 7·5 kV) tracking-test apparatus has been constructed in order to assess the performance of those materials (e.g. dough moulding compounds) that are resistant to tracking and that cannot be graded in order of merit by the test specified in BS 3781 (British Standards Institution, 1964).

*Testing of multishot exploders*

108 A number of visits have been made in co-operation with the Mines and Quarries Inspectorate to NCB workshops where exploders are overhauled and tested in accordance with statutory requirements. Assistance has been given to NCB in the drafting of standard procedures to be followed by the workshop staff carrying out statutory overhauls. Senior workshop staff have also been instructed in the use of the SMRE multishot exploder tester referred to in the 1974 Annual Report (p 32). It is expected that 300 commer-

cially produced versions of this instrument (see plate 4.2) will be supplied to NCB early in 1976, and it will be used at all collieries and workshops for carrying out statutory weekly and quarterly tests of exploders.

109 During the year we also played a substantial part in the production of *Testing Memorandum* No. 5: *Conditions of Test and Approval of Exploders and Related Apparatus* (Health and Safety Executive, 1975), and we were involved in discussions with the Mines and Quarries Inspectorate and NCB on the question of future designs of multishot exploders.

### *Examination of shotfiring equipment*

110 Examinations were made of three multishot exploders and two shotfiring cables that had been impounded by Mines Inspectors. One exploder was satisfactory but the other two were faulty. One of these exploders was found to contain loose particles of metal and two short lengths of wire, the presence of which could have interfered with the exploder's performance. In the other exploder an internal screw which determined the minimum available output was found to have been incorrectly set. This fault could have led to the partial misfiring of rounds. The Mines and Quarries Inspectorate and NCB were notified of these faults.

### *Type-testing of lighting fittings*

111 Ten fluorescent lighting fittings, two floodlights, and one other unit for Division 2, were tested for compliance with certain of the requirements of BS 4533: Part 2 (British Standards Institution, 1969b) and/or BS 4683: Part 3 (British Standards Institution, 1972). Eleven units were successful.

### *Type-testing of portable lamps*

112 Favourable reports have been made on an electric cap-lamp tested for use in the mining industry, and on one tested on behalf of BASEEFA with a view to certification within the terms of BS 4683: Part 4 (British Standards Institution, 1973).

### *Miscellaneous testing*

113 The following items passed tests made in accordance with some or all of the requirements of BASEEFA Certification Standard SFA 3009 (BASEEFA, 1972b): seven ballasts from lighting fittings, two micro-switch units, two encapsulated coil housings, an air-break contactor, a pulser unit, a reed switch probe, a load-break motor switch, a split-pole motor and a television surveillance system. Cable pull tests to BS 4683: Part 4 were also carried out where appropriate, with varying results. The seven ballasts also satisfied tests for compliance with some of the requirements of BS 4782 (British Standards Institution, 1971c).

114 A favourable report was made on a purged and pressurised cubicle designed to house control equipment at oil refineries.

115 Two electronic display units were found to satisfy some or all of the requirements of BS 4683: Part 3.

116 A range of aluminium self-adhesive labels passed tests for resistance to solvents listed in BS 4683: Part 4.

117 A convector heater, an anti-condensation heater and a luminaire were tested to determine their temperature categories, as defined in BS 4683: Part 1 (British Standards Institution, 1971a).

118 Seven units were tested for compliance with various categories of IEC Publication 144 (International Electrotechnical Commission, 1963). Two failed to meet requirements.

## Consultancy service

119 BASEEFA staff provide, on payment, a consulting service for manufacturers seeking advice on the design of equipment that will perform both safely and efficiently in various industries and environments, including off-shore installations. Many types of protection are now available for equipment intended for use in flammable atmospheres, and some are more appropriate than others for use in particular situations.

## Electric shock

### *Electrical safety on building sites*

120 A study of electrical distribution systems on building sites and engineering construction sites has been carried out on behalf of the Building Research Establishment. Recommendations have been made for reducing the risk of electric shock from site electrical equipment.

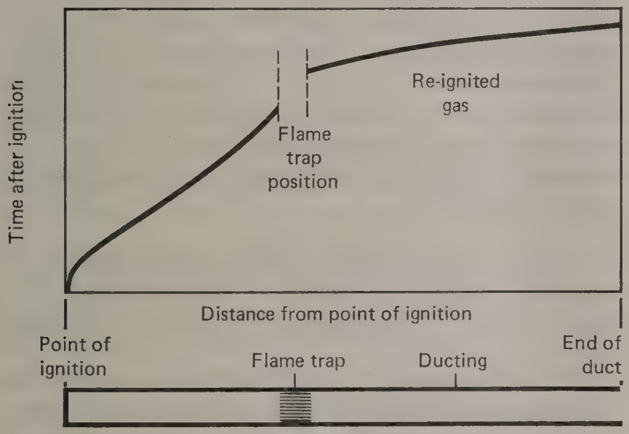
# Vehicles for use in hazardous atmospheres

*Flame-traps for diesel locomotives*

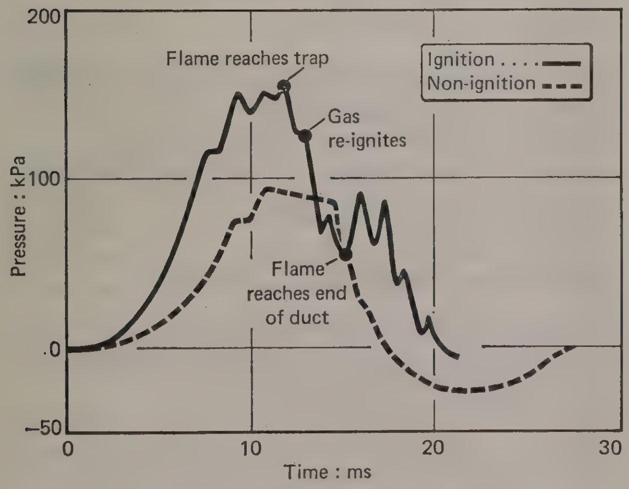
121 The 1974 Annual Report (p 30) described experiments on flat-plate flame traps of the type normally used in the exhaust and air-intake systems of diesel vehicles to prevent ignition of any flammable gas in the surrounding atmosphere. In these experiments a flame-trap is installed in an instrumented duct which is filled with a flammable gas mixture, and tests are made of flame propagation through the trap. During the year extensive flame-speed and pressure measurements have been taken over a range of between 0·3 and 2·5 m on either side of the trap.

122 The apparatus is shown schematically in fig 7a, with a typical flame-speed curve. Following re-ignition downstream of the trap, the flame speed is very much higher than it was in the length of duct upstream of the trap. An increase in speed is to be expected from existing knowledge of flame propagation in ducts, and is largely due to the radical change in the properties of the flow that is produced by passing through the trap.

123 Figure 7b shows two examples of pressure–time profiles taken immediately upstream of the trap: in one the flame is completely extinguished; in the other the gas is re-ignited after passing the trap. The time between the flame front reaching the trap and this re-ignition is of the order of hundreds of microseconds. Pressure measurements immediately downstream of the trap during this time interval give profiles similar to those obtained in ignition behind shock waves. However, the mechanism of re-ignition, and the reasons why ignition only occurs in that region of the duct, are probably related to the mechanism determining the ignition/non-ignition boundary at the maximum experimental safe gap; the relative effects of cooling by entrainment and heating by chemical reaction are involved, and computer programs similar to that described in the 1974 Annual Report (p 26) are being used to study the situation.



(a) Progress of flame along tube : arbitrary units



(b) Pressure immediately upstream of flame trap

**Fig 7** Typical results in study of flame-trap behaviour.

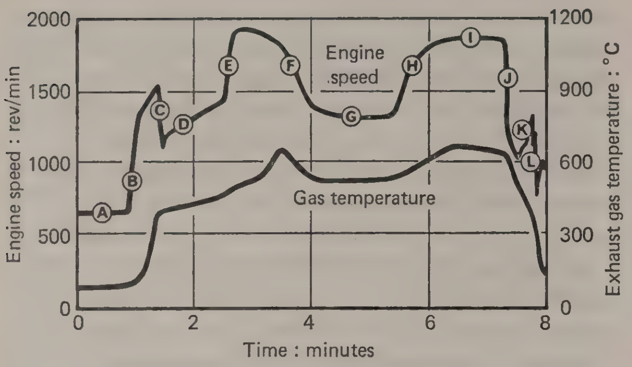
124 When re-ignition does not take place within the duct, it is possible that an ignition might occur when hot gases are ejected from the duct into an unconfined atmosphere. Experiments to study this hazard are being carried out.

125 Trap behaviour with regard to properties such as drag coefficients, pressure loss across the trap, and heat-transfer coefficients within the trap, is being investigated in a steady-state apparatus in which the hot gases from a flame stabilised a short distance upstream from the trap pass through the trap.

*Effect of drawing methane into a diesel engine*

126 Diesel equipment has proved safe in flammable mine atmospheres when fitted with a water-cooled exhaust manifold, a heavy stainless steel conditioner box, and flame traps on both inlet and exhaust. However, the cost of manufacture and the inconvenience of maintenance have prompted a fresh consideration of the problems involved in making diesel engines safe in flammable atmospheres. Apart from the possibility of an ignition caused by the heat of uncooled exhaust gases or as a result of an explosion in the exhaust system, it is also possible that methane in the intake may cause the engine to accelerate to an unsafe speed. This can be prevented with an inlet shut-off valve which cuts off the air supply and so stops the engine. However, an investigation is necessary to discover whether there are any side effects to the use of this shut-off valve that could have adverse effects on safety.

127 A 60-hp mines diesel vehicle with hydrostatic transmission was used for tests. It was fitted with apparatus for recording temperature, engine speed, and other data. Most of the tests were carried out by running the engine in the laboratory with the transmission stalled, a technique that resulted in rather higher temperatures than outdoor trials at full load on a one in three gradient.



| Symbol | Engine action or speed | Principal cause | Symbol | Engine action or speed | Principal cause |
|---|---|---|---|---|---|
| A | Idling | | G | Labouring | Heavy load |
| B | Faster | Throttle opened | H | Faster | Load reduced |
| C | Slower | Transmission loaded | I | Stabilised | Constant load and fuel supply |
| D | Stabilising | Transmission controlled | J | Slower | Methane supply cut off |
| E | Faster | 4·9% methane in intake | K | Faster | Load reduced |
| F | Slower | Load increased | L | Experiment ends | |

**Fig 8** Effect of introducing methane into intake of mine diesel tractor.

128 Figure 8 shows typical results. The temperature was measured at the exit from the exhaust manifold, and showed wide variations with throttle setting and load, as well as with the introduction of methane into the intake. In various tests under heavy load, the exhaust temperature rose as the methane concentration was increased to 5%; above 5% the engine ran unevenly but there was little further temperature increase. If the diesel fuel supply was cut off while methane or propane was being drawn into the engine, the engine quietly stopped because the compression was insufficient to cause ignition. Other higher hydrocarbons would behave differently.

129 When an inlet shut-off valve was first operated on this engine, abnormally high exhaust temperatures (750° to 830°C) occurred. The valve failed to stop the engine because air was being drawn in through distorted and badly fitting joints between the inlet flame traps and the intake manifold. In these circumstances, combustion was incomplete in the engine and fuel was burning in the exhaust manifold. When the inlet joints were repaired the shut-off valve functioned as intended.

130 Other work with inlet shut-off valves sprang from reports that when such valves were operated in conjunction with water-filled conditioner boxes there had been occasions when water was drawn into the cylinders of diesel engines. In our experiments the conditioner box was replaced by a non-return valve, and when the engine was stopped from an on-load condition a negative pressure of 41 kPa (6 psi) was recorded in the exhaust manifold. On a few rare occasions (about 1% of the total) the engine made several reverse revolutions before coming to rest and the negative pressure in the exhaust manifold reached almost 62 kPa.

131 The results obtained in these experiments from one engine may not be typical. Differences in engines, e.g. direct or indirect injection, variations in cylinder-head and manifold design, etc. can be expected to influence the behaviour of the engine when flammable gas is drawn in. The age and condition of the engine may also be expected to influence the results.

### *Type-testing of diesel-engine vehicles*

132 Flameproof testing was undertaken on the inlet and exhaust systems of three diesel engines, all were found to be satisfactory. The three units were also tested for compliance with the requirements of *Testing Memorandum* No. 12 (Ministry of Technology, 1969) for surface and exhaust-gas temperatures and for the concentrations of carbon monoxide and oxides of nitrogen in the exhaust gas. Two of the units passed and one failed.

133 An automatic water make-up system designed to maintain a suitable water level in the exhaust-gas conditioner box was tested and found to be satisfactory.

134 Noise levels were investigated on one locomotive, particularly inside the cab at the driver's head position. As a result of the tests, sound absorbent material is being fitted in the cab in an attempt to reduce the noise to an acceptable level.

135 A dynamometer has been satisfactorily installed in the test laboratory mentioned in the 1974 Annual Report (p 31), and work is in hand to complete the facility by the provision of gas analysis and temperature measurement equipment.

### *Type-testing of ventilated battery containers*

136 Tests on a battery container showed it to meet the ventilation requirements of *Testing Memorandum* No. 11 (Ministry of Power, 1967).

# Explosives

## Explosives used in coal mines

*Mechanism of ignition of methane-air mixtures by mining explosives*

137 The 1974 Annual Report (p 20) reported preliminary studies of the quantities of some of the gases generated when mining explosives were detonated in partly confined conditions in atmospheres containing approximately 4% methane and 96% argon. The results, which have now been supported by further studies, suggest that there is only a small amount of reaction between methane and the detonation products. A fuller utilisation of the results of this work requires the development of methods of estimating the expected behaviour of detonation products of mining explosives as expansion, and consequent cooling, takes place. A small step in this direction has been the development of a simple method of calculating the conditions under which a single chemical equilibrium 'freezes' when the system in which it occurs is subjected to very rapid reductions of temperature and pressure.

138 Other studies are concerned with interpreting the differences in behaviour found during the testing of different batches of explosive of the same chemical composition, and batches of explosives of different chemical compositions, in Break Test Apparatus No. 2. A window of transparent plastic has been installed in the steel sides of the apparatus and high-speed photographic studies, at rates up to 7000 frames per second, have begun. So far the experiments have been made with charges that do not cause a general ignition of gas but each shot that has been photographed shows, near the top plate of the apparatus, a substantial gas ignition which must have become quenched before a general ignition was possible. The phenomenon is rather similar to that observed during studies of the ignition of methane–air by shock waves propagating from a cannon (1970 Annual Report, p 20).

*Transmission and propagation of detonation*

139 In recent years, several instances of suspected deflagration of explosive have occurred in British mines during short-delay firing in coal. This led to an intensification of the study of detonation failure in explosives and the possible subsequent recurrence of deflagration. The study has particular relevance to one possible mechanism by which deflagration might occur in practice; the mechanism is as follows. Gases from an early shot in a round compress and desensitise the explosive charge of a later shot before its delay detonator fires. The delay detonator, which may be up to 60 mm long, detonates and the part of the detonation wave travelling towards the detonator end of the cartridge dies out. The blast produced scatters any undetonated explosive that may be left which may then mix with any coal dust in its vicinity. This mixture and gas in the vicinity may then be ignited and the solid mixture may glow and smoulder.

140 Experimental evidence that such behaviour may take place has been obtained in the course of flash radiographic studies of cartridges of explosive that have been compressed to densities higher than normal and made up in several different diameters, and primed with a delay detonator. In several cases the radiographs show that, for explosive compressed above its normal density, the wave that travels along the cartridge towards the detonator end is much less marked, and thus apparently weaker, than the corresponding waves that have been observed in explosive cartridges of normal densities; this apparent weakness of the wave has been confirmed in some cases by an observed lack of crushing of the detonator tube compared with that which occurs during the detonation of a cartridge of explosive of normal density.

141 The weakening or failure of the wave travelling towards the detonator end of the cartridge may be expected for two reasons. Firstly, the presence of the detonator reduces the cross-sectional area of the explosive and, secondly, this wave is inherently more difficult to establish than the wave travelling in the opposite direction and the difficulty may become significant if the sensitiveness of the explosive has been reduced.

*Development of test procedures*

142 Three procedures are now being used to determine deflagration resistance and each procedure is being examined critically. There is the standard deflagration test procedure (Plant and Barbero, 1969), a recent modification of this procedure, and the method described in the 1974 Annual Report (p 21). The recent modification to the standard procedure consists of replacing the coal-dust barrier, which is placed between the two charges of explosive used in the test, with a barrier of the same length made from a mixture of 50% by mass of coal dust and 50% by mass of the explosive under examination. When sufficient information has been gathered a decision will be made regarding the most suitable procedure on which to standardise.

143 Work is in progress to devise adequate methods for estimating the quantities of some undesirable gaseous components of the detonation products of mining explosives. A theoretical examination is being made of some of the processes involved in the formation and subsequent reactions of oxides of nitrogen.

*Type-testing of explosives*

144 Official tests have been carried out on explosives with the following results: Group P1 explosives, four passed; Group P3 explosives, one passed; Group P4/P5 explosives, four passed; Group P5 explosives, one passed.

145 The development of new types of explosives creates the need for periodic re-examination of

standard tests. Batches of previously approved Group P1 explosives are currently being examined in the blown-out-shot test condition by determining the charge mass for 50% probability of ignition. The results obtained so far suggest that the existing test continues to be satisfactory.

146 During the year 1293 shots were fired in tests on explosives and 15 shots were fired in tests on detonators. These figures include the firings during the examination of impounded explosives referrred to in the next section.

*Examination of explosives impounded by the Mines and Quarries Inspectorate*

147 Permitted explosives and shotfiring materials were impounded after two incidents underground and relevant tests were made to examine their performance from the standpoint of safety.

## Explosives other than those used in coal mines

148 Services and research on the safety of explosives (other than those used in coal mines) were provided for the Explosives Inspectorate by the Royal Armament Research and Development Establishment (RARDE). This is part of the work referred to in paragraph 2 that is being transferred to RLSD's Buxton Laboratory. Table 1 indicates the scope of the work.

**Table 1** Work items received during 1975

| *Items* | *Number* | *Notes* |
|---|---|---|
| Accident investigations | 5 | |
| Ammunition and devices | 44 | Detonators, primers, explosive welders, shaped charges, etc. |
| Amorces and toy caps | 30 | |
| Explosive toys | 16 | Sparklers, snaps, etc. |
| Fireworks | 16 | Shop goods and public displays |
| High Explosives | 11 | Explosives other than those used in coal mines |
| New explosives for inclusion in Authorised List | 8 | |
| Potential explosives | 4 | Pesticides, drugs, etc. |
| Propellants | 31 | |
| Pyrotechnics | 10 | Flares, smokes, etc. |

**Table 2** Non-mining explosives: work items completed

| *Year* | *Imported explosives* | *British explosives* | *Other investigations* | *Totals* |
|---|---|---|---|---|
| 1973 | 68 | 7 | 20 | 95 |
| 1974 | 77 | 8 | 13 | 98 |
| 1975 | 118 | 21 | 35 | 174 |

*Tests and investigations*

149 As shown in table 2 there has been a considerable growth of testing and investigation work in recent years.

150 Each item in the columns 'Imported explosives' and 'British explosives' in table 2 may be anything from a consignment of twenty different fireworks to a variety of complex explosive devices requiring x-radiographic, photographic and remotely controlled 'dismantling' facilities. The 'other investigations' include work on problems such as assessment and classification of new explosives or devices, investigation of accidents, storage problems, and ad hoc research and development work. The large number of miscellaneous problems referred to RARDE that might necessitate a literature search or preparation of a paper, but no experimental work, are not included in table 1. Such work has been carried out for the Explosives Inspectorate on behalf of the United Nations, Local Authorities, Customs and Excise, as well as for the Inspectors themselves.

151 Apart from an increase in imports, the work load has been increased by a number of other factors. Thus, larger samples per work item are being taken, in an attempt to put sampling on a statistical basis rather than to base it on the random spot-checking system that has existed up to the present time. Also more information is being requested, e.g. quantitative chemical analysis of components, assessment of noise from the explosive events, and the effects of storage on explosives. In addition, work has started on the systematic study of explosives by new and often larger scale methods in order to enable the Explosives Inspectorate to implement United Nations' recommendations on the classification and transport of explosives.

*Assessment of hazards of explosives*

152 Long-term studies are being carried out in several fields to improve the assessment of the hazard of commercial explosives. In particular, new and improved methods are being developed for the qualitative analysis of explosives and propellants, on the basis of thin-layer chromatography, gas chromatography, and mass spectrometry. Some effort has also been devoted to improving spot tests. An example of this is an improved test that allows better distinction between lead styphnate and lead azide.

153 Studies of the spontaneous reaction of sulphur with calcium and potassium chlorates have led to proposals describing the mechanism of reaction and further work is being carried out to see if this mechanism can be confirmed.

154 In other work, accelerated storage and life-assessment trials are being conducted to determine the effects of ageing on the properties of explosives.

155 The following is an account of work on hazardous materials carried out on behalf of the Explosives Inspectorate by the Royal Armament Research and Development Establishment (RARDE) at Woolwich during the year. This work is to be transferred to RLSD when the necessary arrangements have been completed.

### *Advice and assistance*

156 Problems associated with bulk and intermediate bulk transport of hazardous materials are becoming increasingly important both nationally and internationally, and advice has to be given on the various problems raised, e.g. the criteria to be applied when assessing the suitability of organic peroxides for bulk carriage.

157 The awareness of the hazards associated with many chemicals and chemical processes is currently increasing. As a consequence, advice and assistance is being sought on an increasing scale by other government departments and by industries etc. on the elimination of such hazards and the disposal of some types of hazardous waste. Examples of such problems are the destruction of explosive azide deposits in drains, procedures to be adopted by the emergency services when dealing with incidents involving organic peroxides, and the disposal of samples of dry benzoyl peroxides found in schools.

158 The assessment of the hazard caused by the storage and use of liquefied petroleum gases in residential premises has been concluded and a documentary film has been made and circulated through the Fire Department of the Home Office to interested parties.

### *Ammonium nitrate based fertilisers*

159 During the year studies have been made of the oxidising power of ammonium nitrate based fertilisers; especial attention has been given to a comparison of the RARDE open-channel test and the Dutch closed-tube test, both of which consist essentially of standard devices for measuring the rate of propagation of combustion along a trail of material. This work arises because of the need for mutually acceptable tests within EEC for establishing whether materials are to be considered as oxidising agents for purposes of storage and transportation. At an international meeting at Woolwich early in 1976 a large measure of agreement was reached on the future programme of evaluation.

160 Other work on these fertilisers during the year has concerned the assessment of their explosability with the 50/70 tube test (Groothuizen and others, 1970). In this test, a standard tube 1 m long, 50 mm internal diameter and 70 mm external diameter, is filled with the substance under test. A donor charge of explosive is used to provide a point source detonative shock. If a propagating reaction takes place, the velocity of the shock front moving through the material is measured by a resistance probe. However, some Canadian work on a large scale has thrown doubt on the validity of the test. In consequence, effort has recently been concentrated on the standard German test which uses a tube of 100 mm internal diameter. The evaluation of this test is expected to take up much of 1976, and a few tests with a tube of 150 mm internal diameter will be needed to establish whether or not reliable results are obtained in borderline cases when the 100 mm tube is used.

### *Calcium hypochlorite*

161 Work on calcium hypochlorite 70% available chlorine is being carried out for a consortium of insurance firms after several major maritime disasters have been associated with the carriage of this substance. A great deal of chemical analysis has been done on many samples of hypochlorite but no relationship between instability and impurity has so far been established, and determining the self-accelerating decomposition temperature (SADT) of the material remains the best way to assess the hazard. The SADT, which is determined by heating the material in an electric oven, is the temperature at which a material begins to decompose spontaneously: once the process has started it continues at an increasing rate. Obviously, this temperature is an important factor in the safe storage and transport of materials. The work on calcium hypochlorite has also included large-scale tests to evaluate the violence of the decomposition of 50-kg drums of the substance.

162 If the problem of transportation of calcium hypochlorite is accepted by the Inter-Governmental Maritime Consultative Organisation (IMCO) as one that needs much greater effort, this effort is likely to involve a study of the effects of packaging on decomposition, and examinations of the effect of water, sea water and trace elements on the SADT of the materials.

### *Nitrocellulose*

163 A number of nitrocelluloses have been submitted for assessment and classification. Work to establish the safest acceptable diluent for use in the transport of nitrocellulose has been completed. Full-scale trials have been carried out to assess the hazards that would arise from the ignition of old nitrocellulose-based film stored in archives. An additional trial, with much fuller instrumentation, is being planned for the near future.

### *Organic peroxides*

164 Organic peroxides are another class of substances that have been submitted for assessment and classification.

165 There are several current research projects dealing with these materials. Firstly, more information is required about their SADTs and work is in hand to develop tests in calibrated Dewar vessels and, if possible to correlate the results with those obtained with the direct scanning calorimeter. There is also a study of the effect of common packaging material on SADTs. Other work on the development of tests is concerned with whether the German BAM 50/60 tube test (Koenen and others, 1961a, 1961b) can be modified so that it is suitable for use with organic peroxides. This test is concerned with the sensitivity of a material to detonative shock. The material is confined in a standard tube and subjected to the detonation of a small standard charge; the acceptability of the material in terms of this test depends simply on whether the tube is shattered.

166 The thermal sensitivity of organic peroxides is often determined with the Koenen apparatus (Koenen and others, 1961b). In this test a quantity of material is strongly heated in a cylindrical tube to which various orifice plates are fixed. The size of orifice that has to be provided to prevent shattering of the tube is related to the rate at which gas is evolved from the organic peroxide. Recent French work using this test on another class of substances has shown that more than one pressure peak may exist, i.e. the tube shattered at two widely differing orifice sizes. A selection of organic peroxides will be investigated to determine whether or not they exhibit similar behaviour. If they do, it will be necessary to amend the present test routine.

167 Another proposed research project involves the setting up of large-scale trials to asess the accuracy with which data can be extrapolated from small-scale tests to the bulk-transport scale. In these tests tanks containing up to 5000 litres of peroxide will be engulfed by fire.

### *Assessment of test equipment*

168 Various items of test equipment are to be installed at the Buxton Laboratory in readiness for the transfer of RARDE work to Buxton. Several of these items are being made and tested at Woolwich. These include two ballistic mortars, which are used to determine the explosive power of materials, and two vessels that are used to assess the explosibility of materials under various conditions. One of the vessels measures the rates of pressure rise of a deflagrating material and the other the rates of pressure rise and temperature rise when the vessel is heated externally.

## Fires

### *Spray-ignition test for hydraulic fluids*

169 The Joint HSE/NCB Working Party on Flammable Oils for Use Underground has agreed that a spray-ignition test based on persistence of burning of hydraulic fluids should continue to be used by the mining industry in Britain. The modifications to the current NCB Spray-Ignition Test described in the 1974 Annual Report (p 36) are seen as providing the basis for a future British test. The Working Party is also taking account of proposals for a spray test for non-mining industries where persistence of burning is not an appropriate criterion; this testing would employ the test cell described in the 1974 Annual Report (p 37). At the request of the Working Party, SMRE is carrying out work to discover how far it is possible to use this type of test cell and associated equipment for testing hydraulic fluids for use in mining.

### *High heat-flux test apparatus*

170 It has long been realised that the assessment of the fire performance of materials by small-scale tests does not adequately reflect the full-scale fire risks of these materials. For example, certain foamed plastics prevent the spread of flame in small-scale tests, yet in large-scale tests they are unable to do so owing to their physical and chemical properties and the different conditions in the two situations. The progress of a fire is governed in part by the rate of emission of vaporised fuel from a material, which depends on the heat flux that the material receives, and by whether the fuel can mix with air to form a flammable mixture hot enough and in a position for ignition to occur. In most small-scale tests the heat flux incident on the sample is low, and usually the sample is positioned in such a way that the heat and vaporised fuel rise away from the fire. Foamed plastics have a high value of activation energy for the pyrolysis reaction; consequently, they burn with difficulty with the low supporting radiations found in small-scale tests. However, because they have very low values of density and thermal conductivity (compared with wood, for example) the rate of temperature rise of foamed plastic surfaces exposed to heat radiation is very high. Thus at high levels of supporting heat radiation, such as would be present in a large-scale fire, the high rate of surface temperature rise is such that the necessary high level of activation energy is reached.

171 An apparatus has been constructed that retains the advantages of speed and economy of the small-scale apparatus, while reproducing the high heat flux and the mixing of evolved products in an ignition zone that are to be found in large-scale fires. This apparatus consists of an electrically heated vertical furnace tube and a pneumatically operated platform which places samples in the lower end of the tube. To ensure uniform test conditions, the heat flux received by the sample is closely defined by the electricity supply and by monitoring the flow of air past the sample. A small gas flame above the sample-burning position provides pilot ignition for the evolved gas.

172 Two values are calculated from records obtained from a fine-wire thermocouple suspended above the burning sample. The delay before ignition gives a measure of the ignitability of the material, and the rate of rise of temperature of the flue gases after ignition gives a measure of the immediate contribution that the burning mass would make to passing on the ignition to the next part of the material in a large-scale fire. This second value may be related to the rate of spread of flame.

173 Work is in progress to relate results obtained from this apparatus to results obtained from medium-scale fire trials on various foamed plastics.

### *Detection of mine fires*

174 In some mines, spontaneous combustion is detected by monitoring the carbon monoxide concentration in samples of mine air drawn continuously through a tube-bundle system to a gas analyser, usually on the surface (NCB, 1972). The air samples can take up to an hour to reach the surface, but this delay is quite acceptable with spontaneous combustion which tends to develop very slowly. This method is not suitable, however, for detecting open fires underground since these tend to develop rather more quickly and the delay could be serious. Transducers designed to detect open fires would need to be sited underground, probably in larger numbers than the present tubes. Electrochemical transducers are likely to be more suitable than those based on infra red since the electrochemical type are intrinsically safe, more robust and cheaper, and should need less frequent servicing. A pitworthy electrochemical carbon monoxide recorder has been constructed for underground trials.

175 A problem would arise in mines that use diesel engines and explosives since the resulting fumes also contain carbon monoxide. There is a need to distinguish the carbon monoxide produced by a fire from that associated with diesel or shotfiring fumes. It has been found that these fumes contain nitric oxide in amounts much larger than have been encountered in the smoke from small open fires. A nitric oxide detector could therefore be used to indicate whether a rise in carbon monoxide concentration was due to diesel or shotfiring fumes, or to a fire. An electrochemical nitric oxide detector has been developed for this application, and it is hoped to subject it to underground trials shortly.

176 In collaborative experiments with the Yorkshire Regional Laboratory of NCB, the gases drawn through a tube-bundle system to the pit surface were directed first to a conventional infra red carbon monoxide detector and then to an electrochemical detector sensitive to both carbon monoxide and nitric oxide. The two detectors gave very similar records except in the presence of diesel or shotfiring fumes, when the electrochemical one gave higher signal peaks owing to the nitric oxide. Only two sampling tubes were used: one at the intake to a district and the other at the return end. The difference in carbon monoxide concentration between intake and return samples is dependent on the rate of production of carbon monoxide by reaction of atmospheric oxygen with the surface of the coal, and on the ventilation rate. Peaks due to the shotfiring fumes were present only in the return sample since these fumes originated within the district. On the other hand, the diesel fumes originated outside the district, and the resulting peaks were present in both sets of samples. The results suggest that the information obtained from this form of district monitoring might well be of value to pit management.

177 Another collaborative investigation has concerned the way in which the readings of carbon monoxide concentration obtained from the standard tube-bundle system may be affected by changes in the ventilation rate and by 'breathing' of the waste in response to changes in barometric pressure. An accurate knowledge of the oxygen deficiency would help in the interpretation of these readings. The Yorkshire Regional Laboratory of NCB has developed an accurate oxygen-deficiency analyser for this purpose, and a brief description of it is given in paragraphs 38 to 40 of the present Report. The results obtained with this instrument for five districts of a colliery over a period of sixty days show that in worked-out districts there is a clear relation between oxygen deficiency and barometric pressure. In contrast, newly developed districts do not show such a relationship as they have little waste area to show a breathing effect.

### *Flammability testing*

178 During 1975, the flammability testing of materials that could be potential fire hazards in industrial premises, and the statutory testing of liquid samples under the Highly Flammable Liquids and Liquefied Petroleum Gases Regulations 1972, were transferred from the Cricklewood to the Buxton Laboratory.

179 The flammability testing of materials is carried out for the Factory Inspectorate which takes any action that may be necessary on the basis of the results. The main test is the determination of the Critical Oxygen Index, i.e. the percentage of oxygen in an oxygen/nitrogen atmosphere in which the material will just burn, in accordance with the standard test procedure of ASTM D2863–70 (American Society for Testing and Materials, 1970). Other tests include the measurement of burning rates of materials in particular oxygen/nitrogen atmospheres. In the course of the year, tests were made at both laboratories on a total of 95 materials.

180 Most of the statutory testing of liquid samples is connected with possible court cases concerned with the storage of 'highly flammable' liquids, i.e. those that have a flash point below 32°C and support combustion below about 55°C. In the course of the year the tests at both laboratories totalled 167.

181 Later in the year responsibility for other research and testing work concerned with flammable gases and liquids was transferred to Buxton from the Royal Armament Research and Development Establishment at Woolwich. Work on these topics will be described in subsequent reports.

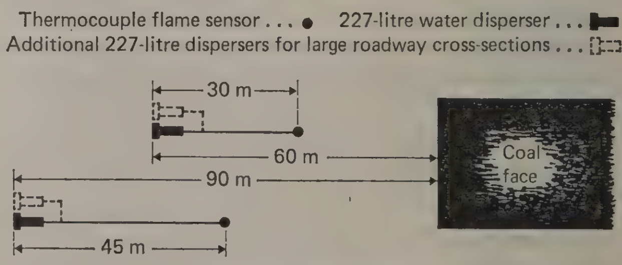
## Dust explosions

*Triggered barriers*

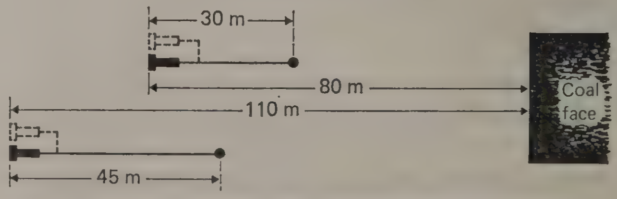
182 Tests have continued in the 366-m Buxton gallery on the 114-litre water disperser for suppressing coal-dust explosions. In order to test barriers under conditions more like those found in coal mines, explosion-proof shelves were designed and fitted between arches in the gallery to carry dust to simulate deposits on roof and sides. The shelves were 190 mm wide and were fitted to each side of the gallery at four heights (0·76, 1·07, 1·65 and 1·96 m). They began approximately 36 m from the closed end and extended for about 78 m along the gallery. As expected the intensity of the explosions was increased by dust deposits on these shelves and, in order to ensure that the explosions should not cause damage to the gallery structure, only deposits containing 50% inert dust were used.

183 The 114-litre water disperser was sited either at 82 m or 91 m from the datum point near the closed end of the gallery with a thermocouple flame sensor placed 30 m inbye of the disperser, or at 102 m with a thermocouple flame sensor placed 40 m inbye. Twelve tests were carried out with a dust deposit containing 50% of inert material placed on the gallery floor and on the shelves. The amount of dust deposit placed on the floor was the same as in previous tests: the amount on the shelves was half that placed on the floor in the shelf area. The explosions were initiated by W-igniters (Rae, 1972) in ten of the experiments and by rockets in the other two. Suppression of the explosions was achieved in all but two experiments. The non-suppressions occurred when the disperser was at 91 m and in both tests the explosions were strong, giving flame speeds at the barrier in excess of 150 m/s. In both instances, the failure to cause suppression was due to an insufficient 'triggering interval', i.e. the time between the sensor sending a signal to the disperser and flame reaching the disperser was too short for all the water in the disperser to have been ejected before the arrival of the flame.

184 The work on these triggered barriers has resulted in SMRE recommendations for a system of such barriers to be used underground. This system comprises two dispersers and two thermocouple flame sensors sited as shown in fig 9 where the roadway cross-section exceeds that of the Buxton roadway so that parts of the roadway are more than 2 m from the water aperture, additional dispersers (also shown in fig 9) will be required to fill in these areas of cross-section. The recommended system uses 227-litre dispersers. In tests at the Tremonia Experimental Mine in the Federal Republic of Germany these dispersers have suppressed faster explosions than those used in experiments at Buxton (1974 Annual Report, p 33). Full drawings are available for the construction of these large dispersers.


Thermocouple flame sensor . . . ●
227-litre water disperser . . .
Additional 227-litre dispersers for large roadway cross-sections . . .
30 m
60 m
90 m
45 m
Coal face

(a) Minimum distance from face



(b) Maximum distance from face (face has advanced 20 m)

**Fig 9** Recommended siting of triggered barrier.

185 Thirteen tests have since been carried out in the Buxton gallery with barriers arranged according to these recommendations. (The recommendations were framed on the basis of many times this number of experiments done previously). Dust deposits on shelves, as described above, were used as well as dust on the floor. The 114-litre dispersers were used, giving a safety factor to the experiments considered as tests of the recommended system. The results of these tests have not yet been fully analysed, but at first sight suppressions were obtained in all of them. The experimental conditions chosen were those thought to produce the most difficult explosions to suppress.

186 The recommendations are being considered by a joint working party representing the Mines and Quarries Inspectorate, NCB and SMRE.

### *Stirred-flow reactor for laboratory coal-dust combustion studies*

187 In 1967 Jenkins and others published an account of an apparatus called a stirred-flow reactor which they used to investigate the combustion of hydrogen and oxygen. A stirred-flow reactor is one in which reactants are admitted at high speed, giving a rapid stirring effect, into an enclosure at the temperature of the reaction expected. The residence time of the reactants can be varied by varying the flow rates and if the required reaction is maintained it can be analysed and the range of conditions for stability measured.

188 A version of this reactor was developed at SMRE in an attempt to study the combustion of coal dust in the laboratory in turbulent conditions similar to those thought to apply in a large gallery. In this reactor, coal dust and air were blown into a 1-litre quartz vessel heated to about 1200 K. This temperature was achieved initially by admitting a flow of a burning methane–oxygen–air mixture to the inside of the vessel. Stable conditions were obtained with residence times of the coal-dust particles of about 100 ms.

189 During the past year some work was done on the SMRE reactor by a research worker of Pennsylvania State University, USA, who spent December 1974 to September 1975 at Buxton. This work was supervised by Professor R H Essenhigh of Pennsylvania State University. In this work is was decided that the residence time should be reduced, and the apparatus was rebuilt so that an increased air flow was available. After the research worker left, work was continued by SMRE staff with the limited objective of completing the programme envisaged by him, that is to measure the volatile content of the output from the reactor. The procedure being used is to stop the reaction as quickly as possible by introducing nitrogen and by cooling with water sprays, and then to abstract samples of the dust by means of cyclones.

### *Testing dust samples for explosibility*

190 The work involved in testing, for explosibility, samples of dusts taken by Factory Inspectors at industrial premises was transferred from the Cricklewood to the Buxton Laboratory in July 1975. The results of these tests are used by Inspectors to enable them to advise factory occupiers on the necessary steps to protect their staff and premises from any explosion hazards associated with the materials and processes they use. The test results can also be used for law enforcement purposes, in cases where regulations are violated, or to help to establish the cause of an accident.

191 The criterion of explosibility is whether or not a cloud of the dust will ignite and propagate flame in a standard verticle-tube apparatus (Raftery, 1975). If the dust is explosible, further information on the maximum pressure and the maximum rate of pressure rise can be obtained with a stronger version of the apparatus.

192 In the course of 1975 the laboratories at Cricklewood and Buxton together tested a total of 208 samples of dust of which 170 were found to be explosible. These include samples of titanium, aluminium, rubber, epoxy resin, grain, confectionery, paper, starch, wood, dried milk, bone, pectin and polyester dusts.

193 During the year 4390 samples of mine road dust were subjected to routine analysis for the Mines and Quarries Inspectorate to ensure that their inert contents were adequate.

### *Gravimetric sampling of airborne dust*

194 A detailed description of SIMQUADS (Safety in Mines Quarry Dust Sampler) was given in the 1974 Annual Report (p 45). The instrument comprises a combined cyclone elutriator and filter assembly, which can be clipped on a lapel, and a pump unit which can be carried on a belt or in the pocket. Since SIMQUADS is to be used in mainly non-mining industries both BASEEFA and Mines and Quarry certificates have been obtained. The instrument is being manufactured for sale by C F Casella & Co Ltd.

195 Further work has been done to improve the filter assembly used in SIMQUADS and also in SIMPEDS, a somewhat similar assembly (Maguire and others, 1971) except that the cyclone and filter are carried on a miner's caplamp. The cassette holding the filter comprised two shells held together by a rubber band which also acted as a seal to prevent air entering the instrument at this point. However, the weight of the rubber band was found to be affected by humidity so that the dust collected could not be determined by weighing the complete assembly before and after sampling. Furthermore, some organisations prefer to use 25-mm diameter silver membrane filters, instead of the 37-mm diameter filters for which the cassette was originally designed, because the silver filters can also be used in a semi-automatic system for analysing quartz by X-ray diffraction. The instrument has been modified to overcome these difficulties: the rubber band is not now required to provide a seal and the cassette and filter can be weighed together. In addition, two types of cassette have been made available to take the different filters. The modifications are now being tested.

### *Continuous monitoring of respirable dust*

196 Development is continuing on two versions of SIMSLIN, a continuously recording dust monitoring instrument which uses light-scattering techniques to give an instantaneous measure of respirable-dust concentrations. The fluctuations in the dust level are recorded on a small chart recorder and, as was shown in the 1974 Annual Report, these fluctuations can be related to various mining activities.

197 The first version of the instrument, which was designed to assess the practicability of the system, is now being improved. The design of the front of the instrument has been altered to reduce the instrument's sensitivity to changes in air speed and work in the dust tunnel has shown that there is now a reasonably good agreement between the readings of SIMSLIN and those of the MRE 113A sampler (the statutorily approved instrument) at different airspeeds.

198 An improved version of SIMSLIN is now ready for underground trials and laboratory assessment. NCB's Mining Research and Development Establishment is also making several copies of the instrument and, when proving trials are successfully completed this will enable us to carry out joint investigations in collieries into the sources of dust and the effectiveness of dust-suppression techniques.

199 A new version of the instrument, SIMSLIN II, is also being developed. The photomultiplier used to detect scattered light in SIMSLIN I has been replaced by a system in which the light is focused on a small solid state detector by an optical condenser system. The detector is less sensitive than the photomultiplier but a new light source has more than compensated for this so that, overall, SIMSLIN II is more sensitive than SIMSLIN I. The signal to background ratio is also better in the new instrument. Moreover, the detector can be used with intrinsically safe circuits and this has the considerable practical advantage that the instrument can be built without the heavy flameproof enclosure that was previously necessary.

### *Helmet for protecting men working in dusty atmospheres*

200 Recent Annual Reports have described a prototype dust helmet which has a built-in fan and filtration system to supply the wearer with clean air; the helmet has a transparent visor to protect the face and also protects the head in the normal way.

201 Work during 1975 has been primarily concerned with field trials of prototype helmets to discover what modifications were necessary before the helmet went into commercial production. Trials have been carried out at coke ovens (plate 4.1) and at aluminium smelters; workers in both types of plant are exposed to particulate fume which it is impractical to limit adequately by conventional dust-control techniques. The trials indicated that for the hot conditions at these plants an air-flow of at least 200 1/min is desirable, particularly in the summer months. Trials were made with helmets having fixed visors and also with helmets having lift-up visors to permit the wearer to eat, drink, blow his nose etc. The lift-up visor was much preferred by the men and, as the tests indicated that an acceptable level of fume protection was still possible, future helmets will incorporate such a visor. Other improvements made as a result of the trials included a headband, giving better air sealing, and some modifications to the helmet shell which will simplify manufacture whilst also giving better balance and easier servicing.

202 The dust helmet did not prove an impediment to normal working and, in general, was well received.

203 The dust helmet is to be manufactured, under licence from the National Research Development Corporation, by Racal-Amplivox Communications Ltd (Beresford Avenue, Wembley, Middx, HA0 1RU).

*Dust suppression*

204 Water sprays are an effective means of minimising the amount of dust becoming airborne, but attempts that have been made to use water to reduce the concentration of dust that has already become airborne have proved ineffective. One attempt made in the past was to spray a water curtain across a mine roadway. In a further examination of this idea a simple theoretical treatment was used to assess the effect of using a spray of bubbles rather than drops and also the effect of electrostatically charging the spray. The results predict that only if a spray is charged is there an appreciable advantage in using bubbles. However, for the spray to be effective, the charge would be so high that it could create an electrostatic ignition hazard. This seems effectively to rule out the idea for use in coal mines.

## Analysis of samples for airborne contaminants

205 Atmospheric contaminants that can have an adverse effect on human health are found in many industrial environments. These contaminants may be fibrogenic dusts, toxic-metal fumes, organic solvents, or substances that affect human cells and lead to cancer or hereditary defects. Inspectors in the field are concerned with determining whether the required hygiene standards are being maintained, or whether the degree of contamination is such that remedial action is necessary. Depending on the circumstances an inspector may take readings himself with his own field instruments, which are supplied and maintained by RLSD's Cricklewood Laboratory, or he may send samples of the contaminated air to the Cricklewood Laboratory, or he may call in RLSD staff to assist in the sampling. At Cricklewood, the samples are analysed with a variety of modern instruments, and many thousands of samples are dealt with each year.

206 The samples sent to Cricklewood are collected in various ways. A large and important group are airborne dust or fume samples which are collected on filters. Another group consists of bulk materials which might be the source of vapours or aerosols that could be injurious to health. A third group consists of air contaminated with gas or vapour: a sample of the contaminated air may be collected or it may be passed through an absorbent to concentrate the contaminant.

207 During the year about 9000 samples were analysed, nearly all of them at Cricklewood and nearly all for the Factory Inspectorate. This is in addition to the samples assessed on site by inspectors and laboratory staff using devices ranging from 'bubblers' or indicator tubes to quite elaborate equipment in mobile laboratories. Table 3 gives information on the numerically more important analyses.

208 The analysis and testing of samples other than for toxicity is described elsewhere in this report. Mine-air samples are analysed for their methane content (paragraph 47), dust samples are analysed or tested for explosibility (paragraphs 190 to 193) and various samples are analysed or tested to determine whether they are fire hazards.

**Table 3** Samples analysed for airborne contaminants during the year

| *Type of agent* | *Number of different contaminants for which samples analysed* | *Number of samples analysed* | *Contaminants for which largest numbers of samples analysed* | |
|---|---|---|---|---|
| Fibrogenic or related airborne particulate material | 5 | 3873 | Asbestos | 2484 |
| | | | Crystalline silica | 1251 |
| | | | Glass fibre | 64 |
| Toxic metals | 22 | 2809 | Lead | 1235 |
| | | | Iron | 188 |
| | | | Nickel | 183 |
| | | | Arsenic | 158 |
| | | | Zinc | 133 |
| | | | Copper | 128 |
| | | | Aluminium | 127 |
| Toxic gases or vapours | 61 | 1577 | Mixed solvents | 316 |
| | | | Bis-chloromethylether | 172 |
| | | | Vinyl chloride monomer | 145 |
| | | | Styrene | 109 |
| Miscellaneous | 19 | 758 | Benzpyrenes | 306 |
| | | | Oil mist | 121 |
| | | | Fluorides | 64 |

# Respiratory apparatus

*Oxygen-producing breathing apparatus*

209 The 1974 Annual Report (p 41) described the development of a breathing apparatus that produced oxygen from the reaction of carbon dioxide and water with potassium superoxide. Recent investigations have concentrated on the rate of oxygen production which is unnecessarily high when the reaction rate reaches its maximum. The reaction can be slowed down, yet still produce more than enough oxygen, by using a drying agent to reduce the water vapour content of the exhaled air. This increases the period for which an adequate oxygen supply can be obtained from a given weight of superoxide. However, the presence of the drying agent leads to starting delays as it takes the superoxide longer to develop a reaction rate capable of providing sufficient oxygen. The examination showed that the extra volume taken up by the drying agent could be used more profitably by replacing the agent with extra potassium superoxide.

210 The problem of starting delays occurs even in the absence of a drying agent. This delay is caused by peroxide forming while the superoxide is still cool, and it has been found that it can be reduced by the addition of certain metal salts which act as a catalyst and help the peroxides to decompose. The catalyst does not increase the maximum rate of oxygen liberation because, in the fully developed reaction, the superoxide is sufficiently hot to decompose all the peroxides without the aid of a catalyst.

211 Testing has now progressed from small scale constant-flow experiments to the use of realistic sized canisters with a sinusoidal flow breathing simulator. A canister has been tested in a conventional closed-circuit assembly in which the inhaled and exhaled air pass through separate tubes. Satisfactory results were obtained at a range of breathing rates from 20 to 100 1/min corresponding to light to extremely heavy work. At present the use of canisters in the simpler pendulum closed-circuit apparatus is being investigated. In this system the exhaled and inhaled air pass through the same tube and through the canister. This uses the superoxide more efficiently, but the inspired air temperatures are higher as the air is drawn directly from the hot canister.

*Suitability of materials for use in high-pressure oxygen*

212 The problem of the suitability of materials for use in the presence of high-pressure oxygen has already received much attention, especially in the aerospace industry where there have been many incidents, some with loss of life, that were directly attributable to the use of unsuitable materials. For many years the compressed oxygen carried in breathing apparatus has been at pressures of 12 MPa (120 bar). Recently apparatus has become available with oxygen at 20 MPa and it is possible that pressures as high as 30 MPa will be used in the future. Because oxygen is a highly reactive gas procedures that may be quite acceptable at low pressures may produce an ignition within the apparatus at higher pressures. An ignition of any of the components would probably render the apparatus unusable and in consequence endanger the life of the wearer.

213 In order to assist the formulation of test specifications and procedures an investigation has begun into the ignition characteristics of a variety of materials in high-pressure oxygen. The mechanism by which ignitions occur is complex and, although the process is not fully understood, the evidence indicates that the contamination of oxygen cylinder valves not only by grease and oil but also by rust, dust, etc. will increase the probability of an ignition. A preliminary survey has been made at a Mines Rescue Station, in collaboration with the Rescue Apparatus Testing Officer of the Mines and Quarries Inspectorate, to determine the rate of contamination of oxygen cylinder valves in daily use. Fifty cylinder valve plugs were examined before they were inserted into valves and again after they had been in normal use for periods of from 3 to 16 months. The rate of contamination was not found to be proportional to the time in service. Subsequently, the insides of some of the cylinders used in these experiments were found to be heavily rusted. Similar experiments are planned with cleaned cylinders.

*Air-line breathing apparatus*

214 Air-line breathing apparatus is now being used in a wide range of occupations where respiratory hazards exist and the freedom of movement of self-contained breathing apparatus is not considered essential. Manufacturers' instructions for such apparatus suggest that multi-outlets and facepieces can be used on the same supply with lengths of narrow-bore hose varying from 60 to 180m.

215 However, the *Joint Testing Memorandum* issued by Government Departments (Department of Energy and others, 1974), which accepts the technical requirements of BS 4667 (British Standards Institution, 1974) as its working basis, does not cover apparatus intended for use with multi-outlets. It was therefore decided to examine a commercially available apparatus to discover the effects of supplying two facepieces from the same hose.

216 Air was supplied to the facepieces at 550 kPa (80 psi) in accordance with the manufacturer's instructions and was taken from the facepieces by the action of a sinusoidal breathing machine. When two facepieces were under test they were connected to the hose by a Y piece, with arms of equal length,

and the facepieces were made to 'breathe' in phase so as to make the maximum demand on the air supply. The air supply could be either constant flow, i.e. the air would flow continuously through each facepiece, whether or not it was being 'worn', or the air could be admitted to the facepiece only by the action of an inhalation demand valve. The results are shown in table 4.

**Table 4** Maximum airflow to facepieces from hose supplied with air at 550 kPa

| *Number of facepieces* | *Air supply: 1/min* | |
|---|---|---|
| | *Constant flow* | *On demand* |
| 1 | 90 | 130 |
| 2 | 39 | 63 |

217 The increased supply in the on-demand condition occurs because the supply lines charge up to full pressure during the exhalation period and this pressure is available on inhalation. The figures in the table may be compared with those given in the 1973 Annual Report (p 44) for experiments to measure the air requirements of men in emergency escape situations. A third of the thirty-nine men taking part in these tests used over 80 litres of air a minute with one man using as much as 102 1/min. The airline apparatus reported on here could only meet this requirement in one of the four conditions examined. Its use with two facepieces is potentially hazardous as the limitations on physical movement imposed on the wearers by the joint air supply are made worse by the restricted air flow.

*Type-testing of breathing apparatus and dust respirators*

218 During the year tests were made on modified facemasks of two compressed-air breathing apparatuses that had been previously approved; two versions of a dust respirator were tested for a manufacturer for compliance with BS 2091 (British Standards Institution, 1969a); and two types of compressed-air breathing apparatus, which supply the wearer with air at positive pressure, were tested for compliance with the relevant parts of the *Joint Testing Memorandum* of the Department of Energy and others (1974). In all cases the results were satisfactory.

219 A project has been started in collaboration with the Factory Inspectorate in which dust respirators are examined before and after trial use in industrial situations. A number of respirators supplied by different manufacturers have been tested, and were able to satisfy the requirements of BS 2091. The results with one manufacturer's respirator clearly illustrated the importance of regular maintenance. Before use the respirator satisfied the requirements of BS 2091, but after use it failed because contamination of the exhalation valve seat resulted in excessive valve leakage. However, when the valve insert and seating had been thoroughly washed in warm soapy water, the respirator was again able to satisfy the requirements.

## Investigation of incidents and disasters

*Firedamp ignitions and mine fires*

220 During 1975 sixty underground fires in coal mines were reported to SMRE by the Mines and Quarries Inspectorate compared with forty-three in 1974 and fifty-one in 1973. Two of the sixty fires were caused by spontaneous combustion. Of the fifty-eight open fires, thirty-six were caused by frictional heating and eighteen by electrical faults. The rest were due to various other causes.

221 Eighteen ignitions of firedamp were reported during the year. Twelve of these were the result of frictional heating during cutting. The most likely cause of two other ignitions was frictional sparking from machinery: one of these resulted in the explosion at Houghton Main Colliery; the other involved a face-conveyor drive-assembly. Three ignitions occurred during shotfiring. The remaining ignition occurred when burning equipment was being used at the top of a disused downcast shaft and molten metal dropped down the shaft.

*Explosion at Houghton Main Colliery*

222 At the request of the Mines and Quarries Inspectorate, SMRE took part in the investigation of the explosion at Houghton Main Colliery in which five men died. The explosion area had to be sealed off, so it was not possible for SMRE staff to examine the site of the accident and almost all the material evidence available came from clothing and equipment brought out with the victims by the rescue teams.

223 The equipment recovered included flame lamps, electric cap-lamps, and self-rescuers. No defects were found in any of the self-rescuers recovered and tested. No evidence was found that any of the lamps examined had been capable of igniting a firedamp–air mixture before the explosion.

224 Some of the items recovered from near the mouth of a heading that had been unventilated for nine days, and could therefore be assumed to contain a high concentration of firedamp, showed signs of relatively prolonged heating. Samples of coal dust taken

from clothing and equipment showed some degree of coking. The small amount of material evidence available was consistent with the theory that a firedamp ignition in the unventilated heading had initiated a coal-dust explosion in a conveyor roadway which increased in violence as it moved outbye. However, there was insufficient evidence to prove the theory.

225 The heading had been left without ventilation because an auxiliary ventilation fan had been switched off when sparks were seen coming from it. The four bolts holding the fan motor in position were reported to have sheared. Experiments were conducted with a 37-kW centrifugal fan of the same type as that used in the heading and with the four bolts removed. When the fan was operated the impeller came into contact with the casing and the resulting frictional sparking ignited a 7% methane–air mixture. The rubbing speed at the maximum diameter of the impeller (0·58 m) was 90 m/s.

226 A scale model of part of the heading and roadway built at SMRE was used to show how, after an ignition at the fan, an explosion could develop in the heading and spread out into the roadway. The results of SMRE's work were given at the Public Inquiry into the explosion and a film of an explosion in the model was shown.

227 The official report on the explosion (Carver, 1976) concluded that the explosion resulted from the ignition of an accumulation of firedamp in the heading that had been unventilated for nine days prior to the explosion, and that the most likely source of ignition was frictional sparking from the fan.

### *Incident at Bedwas Mine*

228 An investigation into an incident at Bedwas Mine, started at the end of 1974, was completed. In this incident the cylinder of a resin injection pump had exploded. Compression-ignition of a flammable mixture of the resin vapour and air in the cylinder was considered to be a possible cause of the explosion. Moreover, the organic peroxide catalyst employed with the resin was found to decompose rapidly in contact with hot metal, sometimes to the point of self-ignition. The use of this resin in conjunction with the pump was discontinued in British mines.

### *Accident investigation in non-mining industries*

229 Since the formation of the Executive, responsibility for providing the Factory Inspectorate with an analytical testing service and with carrying out laboratory work in connection with incident investigations has been transferred from the Cricklewood to the Buxton and Sheffield Laboratories. Topics investigated during the year included spontaneous ignition and other exothermic reactions, misuse of oxygen, and the possible evolution of hydrogen during the processing of bone meal.

230 After a gas explosion in which a man was killed, SMRE was asked by the Factory Inspectorate to examine a gas control unit from a central-heating system. The investigation showed that the flame-failure protection-mechanism had been defeated, so that gas could be released even when the pilot flame was out. This was accepted at the Coroner's Inquest as explaining the presence of the gas accumulation which was subsequently ignited and exploded.

231 The programmes that are being transferred to RLSD from the Royal Armament Research and Development Establishment at Woolwich include rendering assistance to HSE Inspectorates in the investigation of certain accidents in non-mining industries. During the year RARDE gave assistance in nine investigations of ignitions and explosions in a variety of industries: four of these accidents had resulted in fatalities and three had caused injuries.

# Accident studies

*Survey of haulage and handling accidents*

232 In British mines, over a third of the fatal and serious injuries and over a quarter of the injuries for which men take time off work can be classified as either 'haulage and transport' or as 'handling supplies, loose coal, stone etc'. Furthermore, the proportion of the total number of fatal and serious injuries in British coal mines that is to be found within this group has been slowly rising over the past ten years. A survey of those haulage and handling accidents that have resulted in minor injuries is being undertaken by SMRE in co-operation with the Mines Inspectorate, NCB North Derbyshire Area, and the Miners' Unions, to identify in detail the circumstances and situations in which such accidents occur.

233 The technique being adopted is similar to that used in the survey of loss-of-balance accidents in NCB Doncaster Area described in the 1969 Annual Report (p 73). The pit Safety Engineer or Safety Officer selects from his standard accident report forms those accidents relevant to the survey. Then, at interviews with the injured men, he works through a standard set of questions and notes each man's answers on a form specially designed to facilitate the coding and analysis of the information.

234 Haulage and handling accidents are more difficult to investigate than were the loss-of-balance accidents since the associated factors are usually more varied and their inter-relationship more complicated. This made it necessary to devise and test no less than ten versions of a questionnaire before an adequate amount of detailed information could be obtained from an interview of acceptable length.

235 The questionnaire thus produced has been subjected to a trial at a single colliery. The Safety Engineer was asked to obtain information on all accidents in any way associated with haulage or handling operations either underground (except on the coal face) or on the surface. The results of the trial were very satisfactory. The response of the injured men was good, and each interview took between ten and fifteen minutes. Union representatives attended the early interviews and were satisfied with the way the interviews were being conducted. The trial revealed a number of minor difficulties particularly in connection with the selection of accidents to be included. Arrangements are in hand to extend the survey to other collieries in the Area so that details of statistically useful numbers of accidents can be obtained.

236 A joint programme, being carried out by SMRE, the Mines and Quarries Inspectorate and NCB, on the engineering appraisal of underground haulage and transport hazards is described in paragraphs 256 to 258.

*Classification of accident data*

237 In order to design the survey of haulage and handling accidents referred to in the previous section, details were collected of all accidents recorded on the standard NCB accident report forms (form AR1) at three collieries, in one Area, during periods of from one to two years.

238 Analysis of these accident records, 2444 in all, highlighted one of the disadvantages inherent in classification schemes in which each accident has to be allocated to one of a number of categories that are not so tightly defined as to be mutually exclusive. In such classifications the sum of the numbers of accidents in each category equals the total of all accidents, but some accidents could be placed in a number of possible categories and the single-place classification can only show one of these. For example, suppose a man fell down while lifting a derailed tub back onto the track; this could be shown as involving haulage and transport, or manhandling, or loss of balance if these were the categories available. The choice of category used would depend on the judgement of the person performing the classification.

239 For the purpose of the survey it was necessary to identify all accidents that were in any way associated with haulage and transport systems or handling supplies. Hybrid codes were therefore used in the analysis. For example, an accident in which a man triped over a haulage rope was classified as LOB/HT rather than either loss of balance or haulage and transport. This had the effect of considerably increasing the number of accidents to be considered in the haulage and handling group. About half of the accidents were found to be in this group when accidents involving loss-of-balance were included and about a third if they were excluded.

240 In another part of the exercise, these accidents were classified in exactly the same way as in the Annual Reports of the Mines and Quarries Inspectorate. The Reports for the years 1971 to 1974 show that, for the country as a whole, on average 18% of the fatal and serious injuries due to 'mechanical haulage (including self-acting inclines)' were classified as 'derailments or while re-railing'. The corresponding figure for the present survey of all accidents at the three collieries was 31%. If this result should be typical of the situation nationally it would mean that over 4000 injuries involving derailments or re-railing are being recorded annually on AR1s.

# Engineering and metallurgy

*National Committee for Safety of Man-riding in Shafts and Unwalkable Outlets*

241 SMRE is involved in various activities initiated by the Committee formed after the Markham Colliery disaster "to consider all safety aspects of man-riding in shafts and unwalkable outlets and to make recommendations" (1974 Annual Report, p 50).

242 Several mine winding incidents caused by loss of braking efficiency due to brake path contamination have prompted the Committee's Materials Working Group to set up a test programme in which three major British brake-lining manufacturers have agreed to test small samples of some of their own products to determine the effects of various contaminants on their frictional characteristics. The linings under test are of either woven or moulded construction and are exposed to contamination by water, lubricating oil and hydraulic fluid. The test programme has been devised by SMRE in collaboration with NCB and the manufacturers, and every effort has been made to standardise the procedures used by the manufacturers, to ensure that the results are comparable. Large-scale tests on a typical winding engine will be considered when the small-scale results are available.

243 In the Committee's Working Group on Design, SMRE, and NCB's Mining Research and Development Establishment have continued their collaboration on work that will eventually form the basis for a design guide for winding gear components (1974 Annual Report, p 56). It is intended that the guide will recommend design criteria for components in winding installations, against which existing components can be checked, and new ones designed: it will also give advice on design and inspection procedures for avoiding fatigue failure. The code will deal first with winding engine brakes. In addition to the strain gauge tests on brake components reported last year, SMRE has undertaken a laboratory study of the magnitude and distribution of stresses in the bolts of brake anchorages.

244 The Committee's Working Group on System Reliability has been greatly assisted by The Safety and Reliability Directorate (SRD) of the United Kingdom Atomic Energy Authority, which has carried out a reliability assessment of safety aspects of a modern winder under a contract placed with SRD by NCB. Each component in the installation is assigned a failure rate, based on past performance, which is taken into account when the reliability of the system as a whole is quantified. SMRE has played a major part in the retrieval, from the records of the Mines and Quarries Inspectorate, NCB, and SMRE, of information on failures of mechanical winding gear components over several decades.

245 Reports by each sub-committee and working group of the whole National Committee on their work so far will be published or summarised in the Report of the National Committee, Part I, in which the principles behind the recommendations that have already arisen from the work of the Committee will also be discussed.

*Design of cage-suspension gear*

246 SMRE has continued to provide assistance for an NCB Committee concerned with the rationalisation of cage-suspension gear. Last year the Committee agreed that a cage-suspension chain assembly of recommended design should be submitted to static and dynamic testing at SMRE (1974 Annual Report, p 51). These tests have now been completed and the results show that the design is satisfactory. It will now be possible to specify a rationalised range of designs for different payloads.

*Non-destructive testing of wire ropes*

247 A contract has been placed with Plessey Radar for the development of an instrument that will use new magnetic techniques for the non-destructive testing of locked-coil ropes. A preliminary feasibility study has shown that it should be possible to design a single instrument that will detect gradual changes such as wear and corrosion, and also local defects such as wire breaks, even when any of these changes or defects are close to the centre of the rope. Testing is being carried out on specimen ropes with an experimental rig with the object of confirming this; a specification for a prototype instrument will depend on the results of these tests.

248 Plessey Radar have also been examining the feasibility of analysing non-destructive test records by fast Fourier transform techniques. SMRE has supplied data for this work, obtained by measurements with the Polish MD6 Defectograph on ropes in service. The signals were recorded not only on the standard chart but also on magnetic tape for computer analysis. The results are promising, but further work is necessary before this analytical technique can be used in an actual instrument by, say, incorporating a micro-processor.

*Fatigue strength of cappings for mine winding ropes*

249 The 1971 Annual Report (p 55) described tests to discover how polypropylene, used instead of natural fibre for the cores of wire ropes, would be affected by white-metal capping. The heat of the capping process was found to have a detrimental effect on polypropylene fibre, which melts at about 130°C: the re-solidified core is more brittle than the original fibres, and also, in all the cappings examined, a

cavity had formed between the white metal and the core. A new 500-kN (50-tonf) fatigue machine, suitable for testing lengths of capped rope, has recently been commissioned at SMRE. Preliminary results comparing the fatigue life of white-metal cappings formed on ropes with synthetic-fibre and with natural-fibre cores have been obtained. The full programme aims to evaluate several combinations of rope types and terminals and to compare their fatigue lives for the increasingly intensive duty involved in modern mine shafts.

### *Pit-bottom buffers*

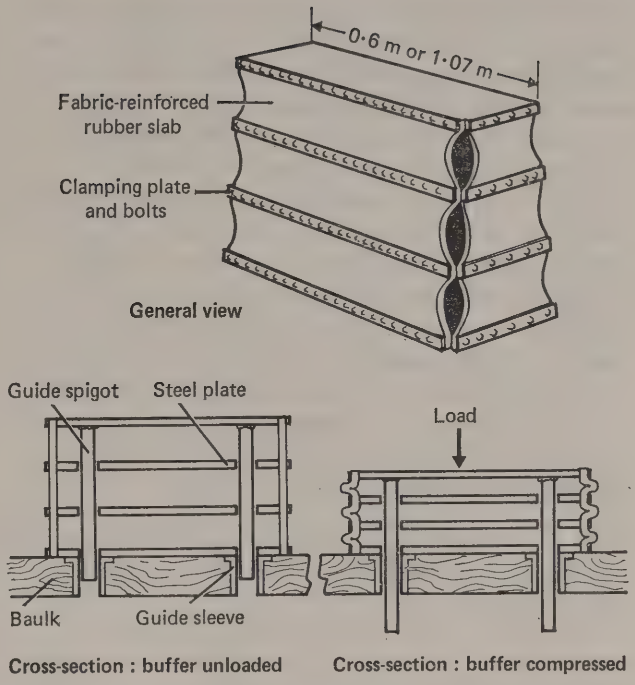
250 The official report of the disaster at Markham Colliery (Calder, 1974) commented "The accident would not have been so serious if, instead of landing baulks, an arresting device had been installed below the lowest winding level"; it was therefore recommended that all solid landings be replaced with suitable arrestors as soon as possible.

251 The National Committee for Safety of Manriding in Shafts and Unwalkable Outlets (see paragraphs 241 to 245) has considered various existing and proposed designs. Ideally an arrestor should withstand repeated impact from the cage as it lands during normal winding operations, and in an emergency, should absorb, with minimum rebound, the energy of the cage travelling at abnormal speed.

252 A buffer produced by a manufacturer for NCB is shown at fig 10. The buffer is made of fibre-reinforced rubber slabs, bolted to steel plates, and is designed to absorb energy by outward flexure of the rubber slabs. The buffers were tested initially in a shaft at a disused colliery by NCB's Mining Research and Development Establishment.

253 Five buffers have now been tested at SMRE: three of the three-tier version shown in fig 10 and two of a four-tier version. Both static and dynamic tests were made on individual buffers, the former by loading buffers in a hydraulic press and the latter by subjecting them to impact in the Buxton impact machine (1964 Annual Report, p 18). Broadly speaking, the results obtained by SMRE agree with those obtained in the colliery tests.

254 Results obtained at SMRE show that the buffers do not behave consistently under static and dynamic loading. Under repeated loading they lose some of their stiffness and thus some of their energy-absorbing capacity. Results for the four-tier version were close to the performance specifications for oil buffers used in lift installations etc. given in BS 2655: Part 1 (British Standards Institution, 1970). In these circumstances, NCB has decided to conduct pilot tests of the buffers in three shafts.



General view

Cross-section : buffer unloaded

Cross-section : buffer compressed

**Fig 10** Experimental pit-bottom buffer.

255 The choice of materials and designs that can be used in cage arrestors is conditioned by the space available under the cage in its normal stopping position near the shaft bottom, and SMRE is investigating the energy absorption characteristics of various materials and devices to see if the available space can be used more effectively.

### *Haulage and transport accidents*

256 Since 1968 'haulage and transport' has replaced 'falls of ground' as the major cause of fatal and serious underground accidents, and the Annual Reports of the Chief Inspector of Mines and Quarries have repeatedly drawn attention to the seriousness of the situation.

257 As part of the effort to reduce these accidents, a Haulage and Transport Accidents National Steering Committee has been set up under the sponsorship of H M Chief Inspector of Mines and Quarries, the Director General of Mining, NCB, and the Director of Research and Laboratory Services, HSE: Committee members are drawn from NCB, the Mines and Quarries Inspectorate and SMRE. The Committee's terms of reference include determining where problems lie and how they may best be treated, and allocating the resources, provided by the organisations concerned, to carry out the work.

258 One of the problems was that we were not able, with existing data, to decide where engineering improvements in systems, operating methods or equipment would lead to the greatest reduction in

hazards and accidents. Accordingly, at its first meeting early in 1975, the Committee adopted proposals that investigating teams should be set up. During the year, three teams each of four engineers (two from NCB and two from SMRE) have been studying current underground haulage and transport practices throughout the UK coalfields, and have visited eighteen collieries, selected to include all the main haulage and transport systems. The teams are concerned not only with identifying engineering developments that are likely to have a major effect on safety but also with seeking out local safety features and devices whose wider application could be recommended. Work will now be concentrated on engineering improvements in specific hazard areas where it is expected that the greatest benefits in safety can be effected.

259 A statistical survey of minor haulage and handling accidents at selected local collieries is described in paragraphs 232 to 235.

### *Fires on conveyor idler rollers*

260 An account was given in the 1973 Annual Report (p 56) of the way in which roller bearings could become contaminated with dust by 'breathing'. Dusty air passes in and out of the roller interior through the bearing seals as a result either of barometric pressure changes or pressure changes due to the repeated heating and cooling of the air within the roller with the intermittent running of the conveyor. Further tests have been made on the new design of commercial roller described in the 1974 Annual Report (p 51). The seal assemblies on the unused examples supplied were successful in preventing breathing, although worn seals which had experienced severe service in a china-clay mine were not. Local dust accumulations could be ignited in the extreme conditions that occurred when a seal was removed to expose the bearing to a heavy dust cloud. Other tests have now been conducted under severe rather than extreme conditions: the roller was run in a heavy dust cloud with part of the seal removed to leave an annular gap of about 1 mm between seal and shaft to represent damage or heavy wear. In these conditions the roller generally took longer to fail than some rollers of earlier design, but in some cases the roller shaft near the bearing became hot enough to ignite coal dust that accumulated at the end of the roller.

261 Other ideas to eliminate breathing problems are being tried out underground in collaboration with a manufacturer. They include two SMRE designs to reduce the likelihood of air movement through the seals: in one design the roller interior is vented and both sides of the bearing are sealed; in the other design, the air space inside the roller is reduced to a minimum. In a third design, developed by the manufacturer, both sides of the bearing are sealed but the interior is not vented.

262 Work to investigate the view widely held in the mining industry, that a roller that has become locked is not likely to ignite coal dust, even though the belt continues to slide over it, was mentioned in the 1974 Annual Report (p 52). In recent experiments on a surface conveyor at a colliery the friction of a loaded belt running over a single locked roller did not produce temperatures likely to ignite coal dust when the belt was damp and when the roller loading was within the NCB Specification for a return idler (NCB, 1969). Further investigations to establish the effect of belt condition, higher roller loading, and consecutive locked rollers, are in hand.

### *Fatigue-crack growth in 1·5% manganese steel*

263 All metallic components contain flaws in the form of inclusions, imperfections, surface scratches, etc. A study of fracture mechanics is used to assess how critical a certain flaw is with respect to a known working load. If a flaw is above a critical size, then application of the working load will cause failure of the component. It is also important to study mechanisms by which a very small sub-critical flaw can grow to become critical. The most important growth mechanism is fatigue, a process resulting from cyclic or fluctuating loads. The rate at which fatigue cracks can grow in a steel component naturally influences the safe working life of the component. The frequency of inspection for such cracks must be carefully considered in relation to fatigue-crack propagation rates so that the component can be withdrawn from service well before a crack reaches a critical size. The aims of the present work are to establish what metallurgical factors affect the fatigue-crack propagation rate under specific loading conditions in critical components of colliery winding gear made from 1·5% manganese steel to BS 2772 (British Standards Institution, 1956).

264 In an initial programme of work, fatigue-crack propagation rates in notched test pieces have been measured by using an electrical potential-drop technique to monitor the crack growth. In this technique a constant current is passed longitudinally through the test piece, and the potential drop across the crack increases as the crack propagates across the test-piece section from the notch. Tests made with two types of notch-bend test pieces (10 mm × 10 mm and 13 mm × 26 mm cross-sections) have confirmed the accuracy of the technique.

265 Other tests have been concerned with determining the effect of microstructure on the characteristics of fatigue-crack growth. Two microstructures of

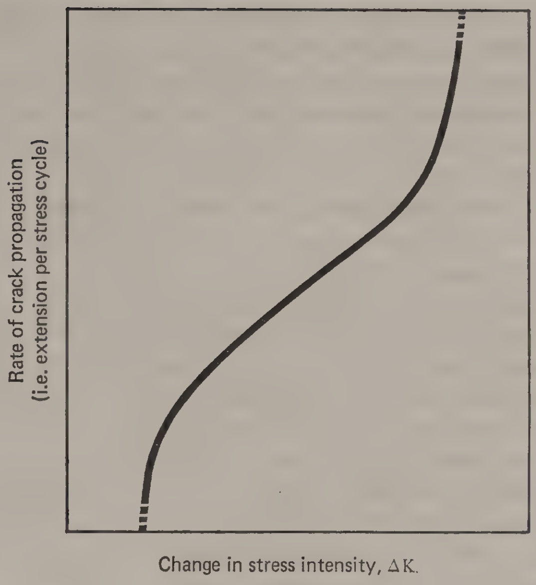
differing yield strengths were used and, for each one, a curve was obtained for the relation between fatigue-crack propagation rate (i.e. the extension of the crack per stress cycle) and the change in stress intensity △K that occurs at the crack tip during the cycle. Figure 11 shows the sort of curve that is obtained. The essential features are an initiation or threshold value of △K below which cracks will not grow, a middle linear region of crack propagation, and an upper portion where the fracture-toughness value of the material is approached. (The fracture-toughness value is the critical value of stress intensity above which catastrophic failure will occur).

266 The results showed that, in the middle linear region in the two cases tested the relation between crack-propagation rate and △K was independent of microstructure and hence yield strength. In contrast, the results of earlier work with more conventional techniques suggests that fracture-toughness values and initiation levels will vary with microstructure.

267 Future work will be concerned with looking quantitatively at how the total fatigue life is affected by initiation, propagation and toughness characteristics, bearing in mind that the initiation and toughness characteristics are, in general, dependent on microstructure.

*Metallurgical and engineering examination of broken and defective equipment*

268 A summary of some recent investigations of equipment failure carried out at SMRE has been published together with discussions of the lessons learned, Jeffrey and White, 1976); further reports are planned.



Where $\Delta K \propto \Delta\sigma a^{1/2}$

$\Delta\sigma$ = difference between maximum and minimum applied loads

a = crack length

**Fig 11** Qualitative representation of change in rate of crack propagation during fatigue cycling.

269 During the year under review, sixteen instances of equipment failure were studied in depth at the request of various Inspectorates. They included five rope failures, a tower crane failure, two chemical plant failures, and metallurgical and engineering investigations of various smaller components from mines and factories.

# Safeguarding of machinery

270 A new section has been set up by RLSD to study the safety of industrial machinery. Initially, the section is concerned with safety assessment and the improvement of photo-electric and mechanical guards used to prevent operatives being injured by machinery.

271 Work has begun, in co-operation with the Factory Inspectorate, on photo-electric guarding systems used with press brakes and guillotines. A guarding system must always be considered in relation to the particular machine for which it is intended and, for this reason, a necessary preliminary is to determine those characteristics of the machine that could affect the efficacy of the guarding system, e.g. its speed, the reliability and effectiveness of its braking system, the stopping time etc. The guarding systems themselves are studied first by a close examination of the circuit plans and then by setting up the systems on a circuit simulator so that the electric and electronic logic of the circuits may be analysed. An important part of the study is to ensure that in the event of breakage or malfunction of one or more components the system will always fail to safety. Tests are also conducted on actual components to determine the time constants and other characteristics of relays and braking systems. Final studies are made on guarding systems fitted to complete machines working in factory environments.

272 Apart from assessing the efficacy of certain guarding systems in relation to particular machines, the study will gradually build up a body of knowledge that will be of value not only to ourselves but also to Inspectors and to manufacturers, and should give a much clearer idea of the merits of the various guarding systems and of the confidence with which they may be applied to different types of machinery. For example, we have now started to study, in collaboration with the Factory Inspectorate, the problems involved in the application of photo-electric guarding systems to wool warping and beaming machines.

273 Another subject of study is the guarding of rotating machinery in a range of industries that includes food processing and laundries. These machines are sometimes large and heavy and have the common characteristic that they continue to rotate long after their power has been switched off. Clearly a system that simply prevents factory operatives from opening the mechanical guards when the power is on does not provide an adequate safeguard. However, at present no single system exists, in a widely applicable form, that will prevent an operative from opening the guards before the machinery has come to rest. An investigation of this problem has therefore been undertaken and it is hoped to develop better rotation-sensing devices than those at present known so that, through interlocking arrangements, the guards cannot be removed while the machinery is still rotating.

274 An investigation that has been completed concerned some of the safety and operating aspects of triple roll mills, used in industry in the manufacture of paint, printing ink, plastics, etc. These mills consist of three large diameter steel rollers running together, but driven at different speeds, so that they are in rubbing and rolling contact where they touch. Mill operatives pour pre-mixed paint etc. into the nip or in-running junction of the first and second rollers, and the action of the mill ensures a homogeneous dispersion of pigment particles in the oil, varnish, or other liquid medium. Factory Inspectors have held the view for some time that the nip is a dangerous part of the machine, particularly during the cleaning-down process.

275 A series of trials were conducted in the Sheffield laboratories with a mill lent by a printing ink manufacturer and fingers simulated with pieces of oxtail and lamb's tail obtained from a butcher. The trials showed that these machines are liable to trap fingers especially when the rollers are clean and dry and separated by a gap of something over a millimetre such as an operator might set up during the cleaning process. The machine's performance was not made worse, as some users had believed, by a nip or safety bar set along the in-running junction of the rollers, and it was found that a closely fitting nip bar virtually eliminated the risk of trapped fingers. The account of this work published by Crorkin and Matthews (1975) recommends that a nip bar be fitted as standard practice and interlocked so that the machine cannot be run unless the bar is in position. The bar could be taken out to be cleaned, at which time the machine would be inoperative.

## Nuclear installations

276 When reviewing reactor systems and other nuclear plants at the conceptual, design, construction, and operating stages, the Nuclear Installations Inspectorate has to make judgements on a very wide range of technical and scientific issues. It is important that these judgements are made against an independent frame of references, and also that staff who are called upon to make these judgements have a sufficiently intimate and up-to-date appreciation of the technicalities of reactor and nuclear plant safety. It is also sometimes the case that judgement must be made on technical matters of such a specialised nature that the required technical knowledge may not be available within the Inspectorate. Also, in the interests of efficient use of manpower, it is sometimes better to call on outside support. These are among the principal reasons why the Nuclear Installations Inspectorate has developed a programme of extramural work and also calls on the services of more than twenty external consultants, some of whom are involved in the extramural work itself.

277 Where it is felt that a problem needs to be examined, the work is carried out by a suitable agency, under contract to the Executive, and supervised by a professional representative of the Nuclear Installations Inspectorate. It is not the objective of any of the work sponsored by the Inspectorate to resolve problems of design or to conduct research into specific problems of the safety of nuclear installations. This is the responsibility of design and resaerch organisations within the UK nuclear industry. The programme of support is therefore planned in content and scale to provide a basic understanding of safety considerations from sources that are, so far as possible, independent of the nuclear industry.

278 A substantial part of the support work consists in studies or analyses in which theoretical models are used to provide information about the behaviour of particular systems. This work involves complex and extensive calculations. The form of these studies is specified by the Nuclear Installations Inspectorate in consultation with the contractor. Other support takes the form of laboratory experimental work in which phenomena of general interest relevant to plant safety are studied. Information on recent or current projects is given in Appendices I and II.

279 A notable feature of the current extramural programme is that about two-thirds of the funds are spent on work in support of the Inspectorate's studies of systems such as fast reactors, steam-generating heavy-water reactors, and light-water reactors where the commercial application is new to this country.

## Occupational medicine

280 The bringing together of hitherto independent Inspectorates within the Executive has resulted in a need to widen the scope of the research programme of the Employment Medical Advisory Service (EMAS). The inclusion of the Alkali and Clean Air Inspectorate, and more recently the Farm Safety Inspectorate, has meant that EMAS must be prepared to provide information and advice on matters arising outside the factory walls and, when industry is responsible for the hazard, even inside the home. Moreover, the extension of the scope of the health and safety legislation to many more people has extended the EMAS sphere of interest into many additional places of work. In the short time that has elapsed since the formation of the Executive it has not been possible to change the general direction of the research commissioned by EMAS. Consequently, the present programme does not show the change in emphasis that is taking place, as it gives no indication of those research projects currently being designed to meet the needs of the future.

281 Most of the EMAS research projects listed in Appendix I are being carried out by the Medical Research Council (MRC) under arrangements specified in Command Paper 5046 'Framework for Government Research and Development' 1972. The Paper provided for increasing sums of money to be transferred from the Research Councils to certain Government Departments over the period of three years starting in 1973. These funds are used by the Departments and now by the Executive to commission research with the Councils.

282 Identification of a need for research into a subject, together with the formulation (in conjunction with appropriate scientists) of the specific hypothesis to be tested and the identification of the benefit likely to accrue, is a lengthy process. For this and other reasons it was not possible to use all the transferred funds on new projects. The bulk of the funds has therefore been used to support work, already being undertaken at MRC establishments and by project grant holders, which was identified either as of direct benefit to the functions of the Executive or which would form a background for further, more directly applicable research. Summaries of two of these projects, which have been completed, appear in Appendix II.

283 A number of new projects have, however, been commissioned with the MRC during the year and these are listed in Appendix I. Five of these (and another three to be commissioned early in 1976) have the common aim of trying to develop a rapid screening system for carcinogenic substances. Another new project is designed to identify the significance of shadows seen on X-rays of the lungs by correlating ante and post mortem radiographic appearances with histological findings.

284 In addition to work commissioned under the 'transferred funds' procedure, EMAS's own research funds are being used to support two projects being carried out at universities. It is planned to use EMAS's funds to commission further projects at universities.

285 A certain amount of research is also carried out within EMAS itself. One of the projects during the year has been a pilot scheme to assess the value of the coproporphyrin test as a screening procedure in the medical supervision of lead workers. The results suggest that the coproporphyrin test fails safely and that the blood-lead test, based on an acceptable limit of 80 $\mu$g of lead per 100 ml of blood, does not. In addition, there is some evidence that the acceptable limit of 80 $\mu$g should possibly be reduced to 60 $\mu$g. Employment Medical and Employment Nursing Advisers found the coproporphyrin test easy to carry out in the factory, and felt that there was a great benefit in having biological information immediately available in the field, rather than having to wait for laboratory results. Also, when the coproporphyrin test was used for screening purposes, there were significant savings in time and money for workers and for medical and laboratory staff.

## Dissemination of Information

*Exhibitions*

286 In November, 1975, the staff providing SMRE's Exhibition Programme became part of the Executive's Directorate of Information and Advisory Services. The staff continue, however, to publicise our research work.

287 Perhaps the most important single item developed during the year was a new lecture–demonstration made in co-operation with the Mines and Quarries Inspectorate, NCB and NUM. This lecture, entitled 'Mine Fires', follows the pattern of the successful 'Firedamp' and 'Keep Dust Down' lectures, each of which has been seen by some 20 000 men. The fires lecture has a simple but very important overall theme – good housekeeping. In 1975 there was a marked increase in the number of fires in British mines. Most of these fires were small but they all had the potential of developing to disastrous proportions with possible loss of life and almost certain loss of a district or even a mine: yet most of them were avoidable. The lecture highlights the main causes of fire underground and describes the precautions, using demonstrations, slides and films. Flame-resistant materials are discussed, the main contributory causes are examined in some detail, and a fire is created in a model roadway to show the behaviour of smoke and the effect of heat on the ventilation system. The lecture is supported by a static exhibition, and a booklet summarising the main points of the lecture will be given to each visitor. The lecture will tour the British coalfields under the auspices of NCB during 1976 and 1977.

288 In other work for the mining industries, contributions were made to National Union of Mineworkers conferences at Skegness and Blackpool, and to the Yorkshire Miners' Gala at Barnsley; and a lecture–demonstration on Fires was given at the NUM National Safety School in Oxford.

289 Supporting material in the form of slides, demonstrations, etc. has been provided in the normal way for various other lectures, including the Alexander Redgrave Memorial lecture given by Mr Bill Simpson, the Chairman of the Health and Safety Commission, at The Royal Institution in London.

290 During the year contributions were made to the International Fire Exhibition and Conference at Olympia; the Offshore Europe Conference and Exhibition, Aberdeen; the International Congress on Occupational Health at Brighton; and the Executive's Flixborough Exhibition at the Industrial Health and Safety Centre in London.

291 Displays showing the results of RLSD's research work were mounted at the Safety in the Chemical Industry: Vapour Hazards, Exhibition at UMIST, Manchester; the One Day Safety Conference and Trade Exhibition at Buxton; and the Dust Control and Air Cleaning Exhibition at Olympia. A new set of display panels dealing with the safety of electrical equipment in the presence of flammable atmospheres was shown at the IEE Conference on Electrical Safety in Hazardous Environments, also held in London.

*Publications*

292 Synopses of recent papers by RLSD staff are given in Appendix III. A list of RLSD publications in print is given in Appendix IV.

# **Appendix 1** Extramural contracts current in the period 1975/76

The contracts are grouped according to whether one of the Inspectorates or the Employment Medical Advisory Service is primarily concerned. The names of the contractors are given in brackets after the contract titles.

Results from contracts marked with an asterisk (*) are summarised in Appendix 2.

The largest numbers of contracts are for work connected with nuclear installations and occupational medicine and a short introduction to this contract work is given in paragraphs 276 to 278 and paragraphs 281 to 284 respectively.

Other extramural work is done at the Royal Armament Research and Development Establishment. This work is being transferred to the Buxton Laboratory and is described in the body of the Report (paragraphs 148 to 154 and paragraphs 155 to 168 and paragraph 231.

## Alkali and clean air

*Investigation of emissions of copper and other heavy metals from copper smelters (British Non-Ferrous Metals Technology Centre)

*Development of instrumentation to monitor stack or duct emissions of heavy metal fumes (British Non-Ferrous Metals Technology Centre)

Lead pollution around industrial premises (Warren Spring Laboratory)

## British Approvals Service for Electrical Equipment in Flammable Atmospheres

Ignition temperature in lighting fittings (Electrical Research Association)

Flameproof cable glands (Electrical Research Association)

## Factories etc

*Influence of flange diameter on the breakage characteristics of straight-sided abrasive cutting-off wheels (Machine Tool Industry Research Association)

Investigation of a range of diving equipment used in North Sea operations (Admiralty Experimental Diving Unit)

Control of welding fume in shipbuilding – contracts shared with sponsors from industry (Welding Research Institute)

*Control of dust and fly in winding and beaming (Shirley Institute)

*Molten metal/water explosions in continuous casting (Aston University)

*Reduction of drop-forging noise – contract sponsorship shared with Drop Forging Research Association (Drop Forging Research Association)

Calibration of noise meters (National Physical Laboratory)

*Lifting gear standards (National Physical Laboratory)

## Mining etc

*Development of instrument for non-destructive testing of wire ropes (Plessey Radar)

Fatigue initiation study of low strength mining steels (Sheffield University)

Electrocatalytic kinetics of pollutants (Southampton University)

Study of organic semi-conductors – under the Science Research Council Co-operative Awards in Science and Engineering Scheme (Kent University)

Catalytic studies with exchanged zeolites (City University)

*Ignition by starting jets (Imperial College, London University)

Effects of vaporised solid inhibitors (Imperial College, London University)

State-of-the-art study on materials for scratch-resistant visors (Rubber and Plastics Research Association)

## Nuclear installations

*Gas-cooled reactors*

*Corrosion of mild steel in carbon dioxide (Wolfson Institute, Nottingham University)

Fretting of steels in carbon dioxide atmospheres (Wolfson Institute, Nottingham University)

*Studies of safety systems in advanced gas-cooled reactors (Nuclear Power Company)

Studies of possible failure modes of pre-stressed concrete pressure vessels (Atkins and Partners)

*Fuel re-processing plant*

Aspects of solvent extraction technology (Bradford University)

Decomposition of butex in nitric acid (Bradford University)

Study of coolant flow patterns and heat transfer from a solid to liquid in a vertically heated annulus (Manchester University)

*Fast reactors*

*Behaviour of fuel during normal and fault conditions (Imperial College, London University)

*Computer analysis of standard faults (Leicester University)

*Whole-core accidents: excursion yield (Imperial College, London University)

Whole-core accidents: post-excursion phase (Systems Information Associates)

*Behaviour of plutonium and actinide after whole-core accidents (1 Associated Nuclear Services: 2 National Radiological Protection Board)

*Containment performance (National Engineering Laboratory)

*Effect of contact between molten fuel and sodium coolant (Manchester University)

*Steam-generating heavy-water reactors* (SGHWR)

*Development of computer program to describe fuel behaviour during a transient (Associated Nuclear Services)

Use of CLAD code to predict strain behaviour of zircaloy cladding during loss-of-coolant accidents (Associated Nuclear Services)

Mechanism of generation and deposition of crud in SGHWR mild steel coolant circuits (National Physical Laboratory)

Studies of zircaloy corrosion properties and the effects of impurities and inclusions (Surrey University)

Study of SGHWR modelling techniques and codes used for fault analysis (Associated Nuclear Services and United Kingdom Atomic Energy Authority)

*Light-water reactors*

*Analysis of loss-of-coolant accidents (National Engineering Laboratory)

Aspects of refilling a reactor pressure vessel after loss-of-coolant fault (Strathclyde University)

Use of computer program to test analytical model against experimental results (Strathclyde University)

Study of film boiling during loss-of-coolant accidents (Manchester University)

Effect of fuel-can swelling on local heat removal by emergency coolant from the fuel (Manchester University)

*Literature survey of work related to reflooding of reactor cores (Associated Nuclear Services)

*Stress analysis of water-reactor pressure-vessel (National Engineering Laboratory and Leicester University)

*Water reactors: general*

*Review of reheat cracking in nuclear pressure-vessel steels (Welding Research Institute)

*Survey of cladding techniques for nuclear pressure vessels (Welding Research Institute)

*Survey of American heavy-section steel-technology programme (Welding Research Institute)

## Occupational medicine

Except where otherwise stated all contracts are with the Medical Research Council.

*Hazards*

Industrial consequences of deficiencies of colour vision

Evaluation of auditory hazards of impulse noise

*Isocyanates: effects on lung function

Long term follow-up of beryllium workers and patients with beryllium disease

Farmers lung and related diseases

Immunopathogenesis of human lung disease due to inhaled organic and inorganic dust

*Cancer of the bladder in relation to occupations in the Newcastle area

Field studies of the incidence of decompression sickness and aseptic necrosis of bone in compressed-air workers and divers, and storage and analysis by computer of the information obtained

Action of asbestos dusts on lung fibroblasts

Influence of soluble and insoluble beryllium compounds in the function of the liver

Induction of enzymes, morphological changes and disturbances of iron and porphyrin metabolism in the liver produced by hexachlorobenzene

Biochemical properties of acrylamide

Metabolism of cadmium

Toxic effects and metabolism of carbon disulphide in rats

Effect of the inhalation of dusts on the physiological properties of animal lungs

Host and accessory factors in the development and progression of asbestos-related pulmonary diseases (New project)

*Screening*

Statistical methods for analysis of radiographic appearances

Development of immunological techniques for surveillance of populations at high risk (asbestos)

Development of a mobile pulmonary function testing unit

Development of methods for scoring X-rays of the chest (Imperial College, London University)

Comparison of lay and medically qualified film readers in radiological classification of pneumoconiosis

Automatic self monitoring device for testing visual function

Computer analysis of chest X-rays in pneumoconiosis

Development of a method for detecting early effects of occupational and environmental hazards

Physical fitness – development of a submaximal test procedure for assessing cardiorespiratory response to exercise

Evaluation of the 'sister chromatid exchange' method in mammalian (including human) cells as a screening system for carcinogens (New project)

Developments of methods for studying metabolism and mutagenic activity of volatile agents (New project)

Application of established bacterial repair and mutation systems to a series of compounds considered as potential industrial carcinogenic hazards (New project)

Development of mammalian cell mutation/variant systems for compounds requiring metabolic activation (New project)

Metabolic activation of carcinogens by mammalian cell or organ cultures (New project)

Correlation of ante-mortem radiographic appearances with post-mortem radiography and histology (New project)

*Miscellaneous*

Audiometry in industry (University of Aston in Birmingham)

Role of lung transamidases

Alignment of respirable asbestos fibres by magnetic fields – biophysical application

Factors determining the development of buoyancy and comfort in fishermen's protective clothing

# **Appendix 2** Synopses of extramural research

Appendix 1 gives a list of the Executive's extramural contracts. This Appendix gives further information on contracts where work has finished or where it has reached a sufficiently advanced stage for some results to be reported. As before, the name of the contractor is given in brackets after the contract title.

## Alkali and clean air

*Investigation of emissions of copper and other heavy metals from copper smelters (British Non-Ferrous Metals Technology Centre)*

The contractor carried out tests for lead, copper, cadmium, zinc, tin and totals particulate matter in emissions from scheduled copper processes at a selected number of sites and by agreement with the companies concerned. This was in order to provide the Alkali and Clean Air Inspectorate with additional data in connection with their statutory responsibilities for air pollution control of such processes. The data obtained are being analysed and used in proposals to the appropriate industries for new standards of emission which are designed to be part of revised best practicable means now being drafted for the processes concerned.

*Development of instrumentation to monitor stack or duct emissions of heavy metal fumes (British Non-Ferrous Metals Technology Centre)*

This contract was to develop a continuous monitor for heavy metals in gaseous emissions from stacks and process ducts. The requirement was to cover lead in the first instance. The design uses atomic fluorescence spectrometry. A prototype instrument has been constructed but certain technical difficulties have been encountered and the equipment is not yet sufficiently advanced or established on a laboratory basis for it to be tried on industrial plant. The original contract ended in 1975 and proposals for a new contract to continue the work are under consideration.

## Factories etc

*Influence of flange diameter on the breakage characteristics of straight-sided abrasive cutting-off wheels (Machine Tool Industry Research Association)*

A test facility was designed and manufactured by the contractor to simulate the breaking of cutting-off wheels in practice and to investigate the effect on safety of flange diameter relative to wheel diameter. Tests were carried out on batches of wheels from different manufacturers using flanges of both 40 mm and 78 mm diameter and three different mechanisms of breakage were investigated. The results of the tests indicated that safety is not compromised by using 40 mm diameter flanges instead of 78 mm diameter flanges for straight-sided cutting-off abrasive wheels up to 229 mm diameter.

*Control of dust and fly in winding and beaming (Shirley Institute)*

This project is concerned with the short-staple process, i.e. it is confined to cotton and man-made fibres and does not include wool. The project, which has another year to run, has reached the stage where an experimental canister has been developed which contains and extracts the dust from the spindles of winding machines. Experimentally this has greatly reduced dust emissions. A provisional patent has been filed and test work under operating conditions is shortly to commence.

*Molten metal/water explosions in continuous casting (Aston University)*

The literature describing explosions that can occur when molten aluminium is dropped into water (e.g. in the course of the continuous casting process) has suggested that the mechanism of explosion is a chemical reaction between molten aluminium and water. However, research at Aston University has shown that other molten materials, such as copper, steel and salt will also produce explosions when dropped into water and that with these materials, and also with aluminium, the mechanism of very violent explosions is more likely to be of a physical rather than a chemical nature. The research, which defines hazards in the foundry industry, is also concerned with producing recommendations for safe practice and some of the ongoing work is aimed at this aspect of the subject. In addition scaled-up field trials are planned and the results of these will be correlated with laboratory test findings if possible.

*Reduction of drop-forging noise – contract sponsorship shared with Drop Forging Research Association* (*Drop Forging Research Association*)

By correlating noise and the vibration of various hammer surfaces it has been shown that the chief sources of noise are the dies and die holders. In the course of work with aluminium test pieces, a significant reduction in noise emission has been achieved by mounting the hammer on springs but there was a slight loss of hammer efficiency. The work is concerned with expressing in terms of equivalent continuous sound level (Leq) the noise reduction achieved by a sprung foundation for hot steel test pieces, and to determine the noise reduction achieved by a rigid screen and by the use of a screen of flexible material for tup, dies and anvil. An attempt to arrange enclosures which overlapped when the dies came together ran into practical difficulties.

*Lifting gear standards* (*National Physical Laboratory*)

In addition to providing technical assistance to various national and international committees, NPL carried out work on various components of lifting gear of which the following were the major items.

Last year, a simple design formula was developed at NPL for the master links of chain slings. This year, work has concerned the treatment of non-circular cross-sections and the assembly of evidence to establish the formula's validity. This evidence was presented at appropriate meetings and, as a result, the formula is now an appendix to the draft ISO chain sling standard.

In his capacity as UK delegate to ISO working group meetings, and as a leader of the UK delegation to ISO sub-committee meetings on hooks, a member of NPL staff provided assistance in the formulation of the delegations' briefs. As a result of this work, some hook stress problems were identified and solved.

The ISO shackle design method was developed at NPL in 1972. Assistance was provided for organisations who have their own particular requirements (e.g. NCB) and wish to adopt this design method. There is now a need for a simple design formula based on the method and work on this has begun.

## Mining etc

*Development of instrument for non-destructive testing of wire ropes* (*Plessey Radar*)

An account of progress in this work is given in paragraphs 247 to 248.

*Ignition by starting jets* (*Imperial College, London University*)

Computer predictions of ignitions in transient jets have been produced, based on finite-difference solutions of the Navier–Stokes equations in two space dimensions and time. The predictions showed good agreement with SMRE photographs of ignitions transmitted through small orifices, which had been taken as part of a programme to examine the flameproof enclosure of electrical apparatus, and also good agreement with the results of experiments carried out at Imperial College on mixing in transient jets, and ignition of a propane–air atmosphere by a hot steady jet. Apparatus is now being prepared to enable the predictions to be compared with ignition of a methane–air atmosphere by a steady jet.

## Nuclear installations

### GAS-COOLED REACTORS

*Corrosion of mild steel in carbon dioxide* (*Wolfson Institute, Nottingham University*)

This work has provided the Nuclear Installations Inspectorate with information on the performance of material in various environments. The results are given in a paper read to the British Nuclear Energy Society.

*Studies of safety systems in advanced gas-cooled reactors* (*Nuclear Power Company*)

The work in this contract is directed towards examination of design features, and has involved studies of cooling-water systems, internal structures, secondary shut-down systems, and essential electrical supply systems.

### FAST REACTORS

*Behaviour of fuel during normal and fault conditions* (*Imperial College, London University*)

The work was concerned initially with adapting the UKAEA computer program FRUMP to operate reliably on the Imperial College computer. This program calculates temperatures and stresses in the fuel and clad, and effects such as restructuring of the fuel, development of a central axial hole, swelling and thermal expansion. A survey is under way into the effects of relevant parameters upon the fuel. So far, the study has examined the influence of operating conditions upon fuel–clad gap and the stress levels in the clad.

*Computer analysis of standard faults* (*Leicester University*)

Computer analyses of standard faults are being done at Leicester University with the intention of improving our understanding of fast reactors in these fault situations and of the performance requirements of protective systems. The studies will go on to examine the behaviour of various core designs with a view to determining, if possible, an order of merit based upon safety considerations.

The program FUTURE has been successfully transferred to the Leicester computer and trial runs have shown satisfactory agreement for test cases. The working of the program is being examined and the sensitivity of its output to mesh size is one area where more detailed scrutiny is required before proceeding with the fault-analysis program.

*Whole-core accidents: excursion yield* (*Imperial College, London University*)

This work is being done with the EXTRA code. The objective is to get the code working, to obtain an understanding of its capabilities and limitations, and then to study the effects of various parameters upon the excursion yield from this hypothetical accident.

The program is now working on the Imperial College computer and a first series of parametric studies has been performed which examined the effect of reactivity spikes occurring immediately prior to the culmination of the excursion. A second series of studies is under way.

*Behaviour of plutonium and actinide after whole-core accidents* (*Associated Nuclear Services: National Radiological Protection Board*)

Associated Nuclear Services completed a study of the behaviour of plutonium and actinides following hypothetical whole-core accidents. The work included the effect of recent revisions in nuclear cross-section data and consideration of the radiological effects of plutonium and actinides.

A more detailed study has now been started with the National Radiological Protection Board, using best estimate values of particle size, atmospheric dispersion parameters, etc. This study goes into more detail in those areas which the early work had shown to be important to the outcome.

*Containment performance* (*National Engineering Laboratory*)

A study is being made of the performance of a typical Commercial Fast Reactor containment. A finite-element mesh programme has been adapted for use in analysing the main body of the vessel for stresses, displacements and temperatures over the 30-year life of the vessel.

The study is being used to give an understanding of the behaviour of such a vessel and, in particular, to predict the limits of stresses and strain throughout the normal operational life and for specified accident conditions which might occur during the reactor life.

*Effect of contact between molten fuel and sodium coolant* (*Manchester University*)

The effect of molten fuel coming into contact with sodium coolant in a fast reactor fault condition is an area where the understanding of the physical processes is incomplete. An experimental study, with appropriate analytical backing, is being carried out at Manchester University to gain a better insight into these processes.
The initial effort has been devoted to study of the collapse of Leidenfrost drops using water at various temperatures. The work will now be extended to sodium, and a sodium facility has been constructed for this purpose and is currently being commissioned.

## STEAM-GENERATING HEAVY-WATER REACTORS

*Development of computer program to describe fuel behaviour during a transient* (*Associated Nuclear Services*)

The development of a computer program to describe fuel behaviour during a transient has been completed. The results of the program have been compared with experimental data, and as a result some improvements have been shown to be necessary.

## LIGHT-WATER REACTORS

*Analysis of loss-of-coolant accidents* (*National Engineering Laboratory*)

An American computer program, RELAP 4, is being used to study certain classes of postulated fault. Work so far has been directed towards establishing the code as a working tool in the NEL computer facility. This has now been completed.

*Literature survey of work related to reflooding of reactor cores* (*Associated Nuclear Services*)

A literature survey has been made of work related to the reflooding of reactor cores after loss-of-coolant accidents.

*Stress analysis of water-reactor pressure-vessel* (*National Engineering Laboratory and Leicester University*)

This stress analysis of a water-reactor pressure-vessel has provided the Nuclear Installations Inspectorate with data for a review of pressure-vessel integrity.

## WATER REACTORS: GENERAL

*Review of reheat cracking in nuclear pressure-vessel steels (Welding Research Institute)*

This report was based on published and unpublished literature reviews, followed by discussions with a number of international experts and companies. It has revealed two forms of cracking: (i) that associated with the heat-affected zone between a base metal and stainless steel cladding, referred to as under-clad cracking, and (ii) cracking in a heat affected zone of a structural weld.

The major result of this study has been to confirm that ASME A533B class 1 and A508 class 3 steels as used in light-water reactors and proposed for steam-generating heavy-water reactors have a low susceptibility to under-clad cracking. Most structural weld cracks form during post-weld heat treatment, but the incidence of such cracking in the above steels was not known. Alternative materials which have been employed have been found to exhibit both faults.

*Survey of cladding techniques for nuclear pressure vessels (Welding Research Institute)*

A report of a literature survey of cladding methods, i.e. wide strip overlay welding, single-wire, and multi-wire, combined with discussion held at a number of international companies involved in such work has been completed. The outcome has been that the main factors controlling cladding quality are now much better understood. No one method has appeared to be superior and different companies have chosen their particular method as a result of development experience. One drawback to cladding that has emerged is that it makes pre-service and in-service non-destructive examination by ultrasonic methods more difficult.

*Survey of American heavy-section steel-technology programme (Welding Research Institute)*

Part 1 of this review, representing a summary of reports studied in the survey, has now been submitted. It gives a general review of a total of thirty-five reports, HSSTP-TR. 1–35 inclusive for the period from July 1969 to December 1973. Its most useful contribution is a tabular presentation of the range of tests, on the HSST plates, weldments, test piece sizes and orientations. Part 2 of the review will enter into a detailed discussion and initial appraisal of the results.

## Occupational medicine

*Isocyanates: effects on lung function (Medical Research Council): J C Gilson of the MRC Pneumoconiosis Research Unit*

A study has been undertaken of thirty-five firemen exposed to toluene di-isocyanate (TDI) during a fire in Bridgwater. Clinical examinations, including a detailed assessment of neurological function and respiratory function tests, have been undertaken one week, six months, and three years after exposure and the results have been analysed (Gilson, 1976).

Help and advice have been given in the analysis of the follow-up of workers exposed to TDI in ICI (Adams, 1975).

Advice has been given to the British Rubber Manufacturers Association in framing the Codes of Practice for isocyanates and also in preparing the protocols for long-term follow-ups in a limited number of factories where the respiratory symptoms questionnaire, ventilatory capacity measurements and occupational histories are being linked to discover whether the present threshold limit standards protect the individuals from any unduly rapid fall of lung function during the course of their work.

*Cancer of the bladder in relation to occupations in the Newcastle area (Medical Research Council): R I McCallum of Newcastle-upon-Tyne University*

A survey was carried out of 246 males and 66 females (312) 89% of whom had a histologically proven diagnosis of cancer of the bladder to determine what, if any, industrial exposure might be related to their illness. Matched controls 229 males and 65 females (294) none of whom had cancer or any renal disease, were interviewed from the medical and surgical wards of the same hospitals.

There was an excess of bladder cancer among males employed in the sugar confectionary industry and the manufacture of paint; females employed in public houses, and for metal furnacemen; commercial travellers; caretakers; an ill-defined group of non-industrial managers, and female teachers. None of these industrial or occupational associations was affected indirectly by smoking.

There was also an excess of bladder cancer among males who had used acid; turpentine/paint thinners; coke dust; and among females who had used medicines, lotions and tablets.

Significantly more of the bladder patients were coffee drinkers than the controls, but their consumption was less than four cups per day. There was no demonstrably significant association between coffee drinking and heavy smoking.

Smoking was demonstrably an exogenous etiological factor, confirming the association between the habit and bladder cancer for males, but because the data were limited, not for females, although a numerical trend existed. 50% of the female bladder cancer patients were smokers while 33·8% of the female control group were smokers.

# **Appendix 3** Synopses of recent publications

*Report No. R3 Mechanical failures: some recent investigations at SMRE*
R Jeffrey and M C White

Each year the Safety in Mines Research Establishment investigates mechanical failures which are referred to SMRE by H M Inspectorate of Mines and Quarries or H M Inspectorate of Factories. This report describes some of the recent investigations. The report is divided into three sections covering general topics, roof supports and wire rope examinations. The cases have been chosen for their variety, and it is hoped that they will be of interest to those who are closely concerned with safety engineering, both in mining and other industries.

*SMRE Technical Paper No. P16 The use of triple roll mills. An examination of safety and operating aspects*
D Crorkin and S A Matthews

Triple roll mills are used in a variety of industries (e.g. manufacture of paints, printing inks, etc.) to break down pre-mixed agglomerates to produce a homogeneous dispersion of particles, each of which is coated with oil, varnish or whatever base material is used.

The in-running nip at the feed end is considered to be the most dangerous part of the machine. The operation of the mill, with and without a protective nip bar, was studied and the results show that the nip bar provided a safeguard without adversely affecting throughput.

*SMRE Technical Paper No. P17 A theoretical study of the flow of mine-air samples in long tubes*
R D Fitzpatrick

The National Coal Board has developed a method of monitoring the concentration of dangerous gases in mine air in which samples from underground sites are drawn through long tubes to a gas analyser at the surface. This note discusses how the concentration/time profile is modified by dispersion during the passage along a tube. The minimum pulse durations at the sampling point to enable an instrument reading of 99% of the original concentration are calculated for a range of tube parameters and times of travel.

*SMRE Technical Paper No. P18 The economics of compressed air as a power source in hot mines*
J McQuaid

The use of compressed air as a power source is recognised as a possible solution to the problem of excessive temperature and humidity in mines. But compressed air is acknowledged to be expensive and quite uncompetitive with electricity when considered as a source of power alone. The possibility that the balance may be altered when account is taken of its potential as a source of cooling, both direct and indirect, as well as of power is considered in this report. A study is first made of the economics of supplying the compressed air direct to a district via a borehole rather than via a pipe in the downcast shaft and an underground distribution main. The advantage, if any, of using compressed air as a power source rather than electric power combined with air conditioning is quantified for a particular set of circumstances representative of those in British mines.

*SMRE Technical Paper No. P19 Optimum cable lengths for intrinsically safe power supplies*
L E Virr

When assessing or testing for intrinsic safety, the energy stored in cable inductance and capacitance must be taken into consideration. Cable capacitance is normally allowed for simply by considering the cable to be replaced by a capacitor having a value equal to the capacitance of the maximum length of cable to be connected. Cable inductance is normally allowed for by considering the cable as a series combination of 'lumped' resistance and inductance. The inductive energy stored in a length of cable depends upon both cable inductance and resistance, and consequently an 'optimum' length of cable often exists which corresponds to a maximum in stored inductive energy when connected with a particular intrinsically safe (IS) system. The latter is normally most likely to be dangerous from the point of view of causing gas ignition with this 'optimum' length of cable connected and this paper discusses the calculation of 'optimum' cable lengths for several commonly occurring types of IS supply.

*The Collection, Analysis and Interpretation of Accident Data*
Edited by W D Hendry 1975 Sheffield: Safety in Mines Research Establishment

A Symposium on 'The Collection, Analysis and Interpretation of Accident Data', organised by the Safety in Mines Research Establishment, was held at Sheffield on 9 to 12 July 1973. This publication is a collection of the papers presented at the Symposium, together with summaries of the discussions.

*Information service on gas detectors*
G Bagshaw *Atkins Computing Services Ltd 'Newsdesk'* October 1975 7 Epsom: Atkins Computing Services Ltd

Information on gas-detecting devices manufactured throughout the world is stored on a computer file; this file can be searched automatically to provide an enquirer with details of all devices in the data-base which have a specified combination of properties (e.g. type of gas, range, cost).

*Electrochemical carbon monoxide sensors based on the metallised membrane electrode*
I Bergman *Annals of Occupational Hygiene* 1975 **18** 53–62

The 'metallised membrane electrode' is made by evaporating or sputtering metal onto a non-porous but gas-permeable polymer membrane. The 'amperostat' system consists of an electrochemical cell with two such electrodes and an auxiliary electrode in a control circuit. The system minimises the effect of temperature on the background current. It also allows the electrocatalytic activation of carbon monoxide sensors to be controlled, and the activity to be maintained. Such sensors, made at SMRE or by collaborators, have given useful results in the field and in the laboratory over a number of years. Preliminary results suggest that, with ancillary equipment, they can make a significant contribution to the measurement of carbon monoxide at concentrations of 10 ppm upwards, and in a wide variety of gases: internal combustion exhaust gases, flue gases, cigarette smoke, exhaled air, polluted air, and air from environments that are subject to spontaneous combustion.

*A simple gas chromatograph with an electrochemical detector for the measurement of hydrogen and carbon monoxide, in the parts per million range, applied to exhaled air*
I Bergman, J E Coleman and D Evans *Chromatographia* 1975 **8** 581–83

The metallised-membrane electrode was developed mainly for use in pocket-sized instruments to measure oxygen or carbon monoxide in coal-mine atmospheres. One version of the electrode which can detect carbon monoxide and hydrogen in air in the ppm range has been used as a detector in a simple portable chromatographic system to allow both these gases to be determined. The application described here is to analyse exhaled air, in order to deduce the carbon monoxide content of the blood and the hydrogen production of bacteria in the gut.

*The use of electrochemical cells in environmental monitoring*
I Bergman and M D Crook *XVI International Conference on Coal Mine Safety Research* Washington DC 1975 Paper III 6

An electrochemical cell consists essentially of at least two electrodes in contact with an electrolyte. In the 'polarographic' type of cell discussed in this paper, gas from the atmosphere reaches the detector or, 'working' electrode by diffusion through a PTFE membrane. 'Active species' in the air such as oxygen, carbon monoxide (CO), nitric oxide or nitrogen dioxide can be reduced or oxidised at the working electrode, and thereby generate a current through this electrode proportional to the partial pressure of the species in the air. The other electrodes serve to carry the cell current, and to set the potential of the working electrode to an appropriate value with respect to the electrolyte. The development of the metallised membrane electrode MME has enabled gas detector cells with improved characteristics to be constructed. Such cells have been incorporated into small portable instruments and fixed-point sampling installations of various kinds. This paper describes these developments under the general headings of 'pocket' (that is to say small hand-held portable) instruments, fixed installations for 'field' use and fixed installations for laboratory use, including chromatographic systems.

*The intrinsic safety of resistive circuits*
B Capp and D W Widginton *Proceedings of the 2nd International Conference on Electrical Safety in Hazardous Atmospheres* (Conference Publication No. 134) 1975 43–47 London: Institution of Electrical Engineers

In inductive and capacitive circuits, the energy dissipated in any electrical discharge is virtually limited to that stored in the reactive circuit components. The ignition mechanisms in such circuits can be largely explained in terms of stored energy, but no such simple approach can be applied for resistive circuits. Here the source of energy for the discharge is virtually unlimited. The paper reviews recent and current SMRE work on the intrinsic safety of resistive circuits and the related problems of the mechanism of ignition by arc discharges.

*A computer-based conversational information retrieval system*
J K W Davies *Symposium Collection, Analysis and Interpretation of Accident Data* 1975 Paper C3 Sheffield: Safety in Mines Research Establishment

The need to use computers in the task of information – retrieval becomes increasingly important as the volume of data grows. A computer-based conversational information retrieval system has been developed at SMRE; it is simple enough to be operated by non-experts typing commands on a teletype terminal connected to the computer.

*Solid state detectors for carbon monoxide*
J G Firth, A Jones and T A Jones *Annals of Occupational Hygiene* 1975 **18** 63–68

The mechanism by which a gas can produce an electrical conductivity charge in a semiconductor is outlined. The resulting advantages and disadvantages in the use of metal oxide semiconductors in gas detection devices for carbon monoxide are described and ways of reducing the disadvantages are discussed.

*The erosion of dust by an airflow*
B Fletcher *Journal of Physics D: Applied Physics* 1976 **9** 913–24

A mechanism is proposed whereby dust is removed from a flat deposit by an airflow; it involves the interaction of the laminar sub-layer of the boundary layer with individual particles. Results of experiments on an isolated deposit are presented to show how the mass of dust removed varies with the airflow velocity and with time. Results obtained with a continuous deposit show that erosion varies not only with time but also with distance along the deposit; this suggests that saltation of larger grains may be taking place.

*The interaction of a shock with a dust deposit*
B Fletcher *Journal of Physics D: Applied Physics* 1976 **9** 197–202

The possibility is investigated that dust can be raised from a deposit over which a shock wave passes by the reflection of shock waves from the underlying surface. It is shown that dust is raised as a result of the rapid flow behind the shock rather than as a result of pressure waves passing through the layer. Dust cloud profiles fit the ballistic trajectories of individual particles having an initial vertical velocity of about 4·5 m/s.

*Materials for winding engine brake systems*
J H Foley and D A Sutcliffe *Association of Mining Electrical and Mechanical Engineers Symposium. The Transportation of Men and Materials in Shafts and Underground* 1975 Paper 5a Manchester: Association of Mining Electrical and Mechanical Engineers

The paper is concerned with materials for winding engine brake systems. The materials selection practice prior to the Markham disaster is outlined and its limitations discussed.

The philosophy underlying the choice of materials for the various parts is outlined and takes into consideration the duties and criticality of the components within the system.

Recommendations for particular materials are given with indentification by reference to British Standards where possible; notch ductile materials are specified for critical components. Difficulties in obtaining some of the recommended materials are considered with some suggestions for overcoming them.

The specification of materials taken in isolation is not sufficient to guarantee the quality of components and the manufacturing processes must be carried out to a standard which will ensure reliability in service. Some guidelines for the production of fabrications and castings are given. The need for adequate control during manufacture, including non-destructive testing, is discussed.

*An investigation of some aspects of flow into gas-cooled nuclear reactors following an accidental depressurisation*
S J Leach and H Thompson *Journal of the British Nuclear Energy Society* 1975 **14** 243–50

This paper discusses a situation that may occur following a depressurisation accident caused by a breach in the heat exchanger circuit of a Magnox reactor. After the pressure within the reactor has fallen to that of the atmosphere, buoyancy forces may cause an outward flow of gas and an inward flow of air. The paper presents the results of model experiments, and gives empirical formulae for calculating the rate of flow that may be induced by buoyancy forces, and the purging flow rate of carbon dioxide that is necessary to prevent the ingress of further air.

*Problems arising from the use of organic plastics in flameproof enclosures*
H Lord and L P Barbero *Proceedings of the 2nd International Conference on Electrical Safety in Hazardous Atmospheres* (Conference Publication No. 134) 1975 59–64 London: Institution of Electrical Engineers

The authors studied the hazard presented by the pressure produced by gases evolving from the rapid application of heat, by electric tracking, to insulating materials. They describe the experimental work, the results, and suggest possible means of overcoming the problem (elimination of organic plastics in future designs, the use of ceramic materials for lead-through brushes, the incorporation of earthed conducting barriers between live parts in combination with a reliable fail safe earth leakage protection system, the fitting of a thermal sensor).

*Airborne-dust sampling for industry*
B A Maguire and G W Harris *Protection* 1975 **12** 3–7

In this paper the authors give an outline of the problems associated with sampling airborne dust, and show how respirable dust may be defined and hence how instruments have been designed to sample respirable dust.

The different philosophies of approach to fixed-point and personal sampling are discussed and various features of ideal dust samplers are considered including air-entry design.

*Recirculating flow in vertical columns of gas-solid suspension*
W E Mason and K V Saunders *Journal of Physics D: Applied Physics* 1975 **8** 1674–1685

Dust-in-air suspensions were produced by feeding dust into the closed upper end of a long vertical tube, of internal diameter 143 mm, open at the lower end. It was found that the falling dust sets up a recirculating pattern of air flows in the tube, in two distinct cells. In the upper cell, air flows downwards near the tube axis, and upwards near the wall, in the lower cell, air flows downwards in a narrow layer of high dust concentration near the wall, and upwards near the axis. This pattern was observed over a wide range of dust feed rates (from 135 g/min to 420 g/min), and for tube lengths between 1·5 m and 3·75 m, it persisted in the presence of a substantial net air flow down the tube.

Measurements were made of air velocity profiles, dust concentration profiles and pressure variation along the tube; from the results a quantitative picture of the air and dust flows is established, and a mechanism is put forward to account for the two-cell recirculation pattern.

*Air entrainment into bounded axisymmetric sprays*
J McQuaid *The Institution of Mechanical Engineers Thermodynamics and Fluid Mechanics Group Proceedings* 1975 **189** 28/75 197–202

The entrainment of air into a conical spray centred on the axis of a short tube is investigated. Dimensional analysis successfully correlates the experimental results of both the present and previous investigations for the case of an unrestricted system. The case where the spray operates against a back pressure, such as might be represented by a length of ducting connected to the outlet, is also considered. Morton's analysis of entrainment into the wake of an isolated body is adapted and some agreement is obtained with experimental results for small flight distance of the drops.

*An approach to the economic assessment of environmental control systems in mines*
J McQuaid *International Mine Ventilation Congress, Johannesburg* 15–19 September 1975

In this paper the problem of determining the most economical method of producing acceptable climatic conditions in mines is considered. There are a number of ways in which the climatic conditions can be controlled. The combination of the changes, produced in the velocity of the ventilation and in the dry-bulb and wet-bulb temperatures determines both the cost and the effectiveness of any particular system. The interaction between cost and effectiveness and the need to satisfy certain practical constraints must be considered in deciding the choice of system. For instance, a system may be capable of producing a change in the dry-bulb temperature at lower cost than the same change in wet-bulb temperature. At the same time a change in the dry-bulb temperature may have a smaller influence on the comfort of a climate than an equal change in the wet-bulb temperature. The need for a systematic approach to the assessment of different systems is thus apparent and in this paper an approach is outlined which, with some further development, can meet this need.

*Possible techniques for the control of heat and humidity in underground workings*
J McQuaid *XVI International Conference on Coal Mine Safety Research* Washington DC 1975 Paper VI 5

In their paper to the 14th International Conference, Mücke and Voss discussed the problem of adverse mine climate and in particular its effect on mine safety and its alleviation by improved ventilation and air conditioning. Adverse climatic conditions have not hitherto been a major problem in British coal mines. Indeed there are no statutory limits to either the dry-bulb temperature or the Effective Temperature although there is a generally recognised need to maintain the Effective Temperature below 28°C.

In recent years, however, climatic conditions in British mines have been tending to approach and in some cases to exceed this recommended limiting value. This has come about for two reasons. Firstly, the power installed on and around a typical face has steadily increased and is now in the region of 750 kW. All of the power output (with the exception of small amounts which are used to elevate material permanently and to increase the surface energy of material by comminution) must be dissipated as heat and removed either by the ventilation air or by some cooling medium piped away from the face. Secondly, the depth of workings has tended to increase, with consequent increased heat pick up by the ventilation air from the hotter strata encountered at depth. Strata temperatures in excess of 40°C have been recorded in British mines. Furthermore, the future changes in mining conditions which can be foreseen are such as to increase the severity of the problem. Greater utilisation of machinery will increase the heat output during working shifts. There will be an extension of workings to greater depths; reserves at depths considerably in excess of 1000 m are now being opened up. The normal fall-off in heat transfer from the exposed strata with lapse of time will have less effect because of the reduced working lives of panels.

There are of course many 'good management' measures which can be taken to alleviate the problem – such as avoiding the use of hot water from machine-cooled systems for dust-suppression sprays, reducing the need for hard labour at the hottest spots, and so on. But there must come a point where positive action to control the climate must be taken. In this paper various alternative courses of action are considered.

*An experimental investigation of some further aspects of the buoyancy-driven exchange flow between carbon dioxide and air following a depressurisation accident in a Magnox reactor. Part 1: The exchange flow in inclined ducts*

A Mercer and H Thompson *Journal of the British Nuclear Energy Society* 1975 **14** 327–34
This paper presents the results of an experimental investigation into buoyancy-driven exchange flows in

inclined and vertical ducts. These flows could occur following a depressurisation accident in a Magnox reactor. The experiments were carried out using a twelfth scale model with brine and water as the working fluids. It is shown that this model satisfies certain scaling criteria. A range of ratios of duct length to diameter and of inclinations of practical interest have been studied. The exchange flows in cranked ducts have also been investigated. The results are given in non-dimensional terms.

*An experimental investigation of some further aspects of the buoyancy-driven exchange flow between carbon dioxide and air following depressurisation accident in a Magnox reactor. Part 2: The purging-flow requirements in inclined ducts*
A Mercer and H Thompson *Journal of the British Nuclear Energy Society* 1975 **14** 335–40

This paper describes an experimental investigation of the purging flow requirements to prevent air ingress into the pressure vessel of a Magnox reactor following a depressurisation accident. The cause of the accident is assumed to be a breach in one of the coolant ducts. The case of a horizontal duct has previously been considered and this report considers purging flow requirements in inclined ducts. A twelfth scale simplified model using brine and water was used. The results are presented in non-dimensional form and their application to the full scale situation is discussed.

*Pollution in mining*
BP Mullins and J McQuaid *IX World Mining Congress* Federal Republic of Germany May 1976 Paper II – 18

The problem of pollutants in British coal mines arising from normal mining processes and the reasons for its increasing severity are reviewed. The possibilities of avoiding pollution at source are discussed and the results of theoretical work at the Safety in Mines Research Establishment relating to the use of separate compressed air power supplies to eliminate some of the troublesome sources of heat contamination of the ventilation air are described. Finally, the use of some local measures to reduce local pollution or its effects on man are considered.

*The use of scale models to study roof layer explosions*
H Phillips *Archiwum Termodynamiki i Splania* 1975 **6** 153–65

The propagation of flame along methane roof layers was studied in a scale model mine roadway, 150 mm high, 100 mm wide and 17 m long. The velocity of air disturbance ahead of the explosion depended on the quantity of gas in the layer, its disturbance, the position of ignition and the degree of roughness introduced in the form of transverse bars at roof level. The disturbance ahead of the flame promoted mixing of the layer with the underlying air and for small methane inputs this was sufficient to extinguish the flame.

*The frictional ignition hazard associated with colliery rocks*
F Powell and K Billinge *The Mining Engineer* 1975 **134** 527–35

Most of the firedamp ignitions in British coal mines occur as a result of coal-cutting machines meeting rock. Petrological examination and rubbing tests on colliery rocks have shown that rocks (other than pyrite) that give ignitions generally contain more than 30 per cent by volume of quartz particles greater than 10 microns, and that the quartz particles are usually larger than 70 microns. An indication of the incendivity of quartzitic rocks can be obtained in the field by the application of a few simple physical tests.

Rock-cutting experiments on a practical scale show that a reduction in pick speed can reduce the probability of ignition and that, at any given pick speed, worn picks increase the probability of ignition over that for new picks. The correct application of water can greatly reduce the probability of ignition.

*The ignition of methane–air by machine picks cutting into rock*
F Powell, K Billinge and DP Cutler *XVI International Conference on Coal Mine Safety Research* Washington DC 1975 Paper VII 7

In 1974, about 93% of coal mined in Great Britain was won by machines. Most of these machines are shearers and trepanners, employed on longwall faces. In recent years more than two thirds of the ignitions of methane–air in British mines have resulted from machine picks cutting into rock. There is no evidence to suggest that any one type of machine is more likely to cause ignition than the others. That is, the number of ignitions occurring with any particular type of machine is roughly in proportion to the number of those machines in use. By far the majority of all machine ignitions occur when coal-cutting machines cut into quartzitic rock in the roof or floor. In the ten year period 1965 to 1974, out of a total of some 150 ignitions produced by machines, 14 ignitions were produced by heading machines. Ignitions have also been reported when machines cut pyrite.

*Assessment of the maintenance of the effectiveness of safety schemes by inspection and age-replacement of protective devices*
JH Powell *Journal of the Institute of Mathematics and its Applications* 1975 **16** 81–92

Expressions are derived for quantities measuring deficiencies occurring in the protective capabilities of safety schemes comprised of devices which are subject to random failure. The devices are assumed to be prone to two modes of failure, one which is readily detectable in service, and one which is undetectable in service. The expressions take into account the effects of preventive maintenance procedures in which devices are inspected at regularly spaced times to discover and renew devices which have failed 'detectably', and also devices are replaced after a specified age in service to mitigate the effects of 'undetectable' failures. These expressions are evaluated for devices having constant failure rate (i.e. exponential failure distributions) for both modes of failure; and also for a constant 'detectable'-failure rate and an increasing 'undetectable'-failure rate (i.e. represented by a second order gamma function failure distribution).

*An interview machine for collecting accident data*
T D Proctor *Symposium Collection, Analysis and Interpretation of Accident Data* 1975 Paper C6
Sheffield: Safety in Mines Research Establishment

A description is given of a machine which has been designed to 'interview' men about their accidents. This machine, developed from a commercially made 'teaching machine' displays questions on a screen; the accident victim responds by pressing numbered buttons. The information is obtained in a form which is easily decoded for analysis by computer. Preliminary trials with the prototype machine at a colliery are reported and discussed.

*A novel method of collecting information*
T D Proctor and N J Cutts *Occupational Health*
1976 **28** 302–07

A questionnaire machine developed at the Safety in Mines Research Establishment is being used to collect information on accidents. The machine is designed to reduce the amount of form-filling, to eliminate the need for interviews and to facilitate the storage and analysis of the data it gathers. The technique has been used in mining but it is expected to find application in other fields.

*Extinction phenomena in liquids*
A F Roberts *Fifteenth International Symposium on Combustion* 1974 305–13 Pittsburgh: The Combustion Institute

A burning liquid is extinguished when its surface temperature is reduced to the fire point of the liquid. The fire point depends on properties of the liquid and of the atmosphere in which it is burning and a theoretical relationship is given which describes this dependence. This relationship is used to calculate the variation of fire point and critical heat loss at extinction of n-butanol with the oxygen concentration of the ambient atmosphere. The proximity of heat sinks to the surface of a burning liquid may cause extinction and this effect was studied experimentally; the data suggested that liquid layers up to 0·5 mm deep were stationary and heat losses from the surface to the heat sink took place by conduction. Effects of convection were apparent for greater liquid depths.

For multi-component liquids, mass transfer in the liquid phase also plays a part in determining extinction behaviour. The effects of the degree of internal recirculation on the relationship between the mean composition of a liquid mixture, the surface concentration and the composition of the evolved vapour are discussed. Data illustrating the importance of these effects are given for the ethanol/water system; the minimum concentration of ethanol which would sustain burning in air varied from 7 to 45%, depending on the degree of recirculation within the liquid.

A burner was developed in which the effects of heat and mass transfer in the liquid phase and the oxygen concentration of the surrounding atmosphere on the extinction of a burning liquid could be studied. Some early experiments with this burner are described.

*Dust sampling with the continuously recording instrument* SIMSLIN
R J Seaney and D Barker *Colliery Guardian* 1975
**223** 532–33

The Safety in Mines Research Establishment has recently developed a continuously recording instrument, SIMSLIN, for monitoring the airborne concentration of respirable-size dust. Details of the instrument and its performance in various dust clouds generated in the laboratory have been published elsewhere. SIMSLIN has full Intrinsic Safety and Flameproof approval for use in coal mines and is now being used in a series of underground proving trials. This article gives some examples of the results obtained so far.

*Experimental use of a paper questionnaire*
C R Senneck *Symposium Collection, Analysis and Interpretation of Accident Data* 1975 Paper C5
Sheffield: Safety in Mines Research Establishment

The experimental use of a paper questionnaire designed to elicit detailed information about the circumstances of loss-of-balance accidents in coal mines is described. The experiment ran for nearly two years throughout the Doncaster Area of the National Coal Board and involved injured men being interviewed by their colliery Safety Officers. The coverage and accuracy of the responses are considered and an example is given to show how the information obtained can lead to remedial measures. It is concluded that an interview/questionnaire system is a practicable method for collecting detailed information about particular types of accident.

*Over-3-day absences and safety*
C R Senneck *Symposium Collection, Analysis and Interpretation of Accident Data* 1975 Paper A1 Sheffield: Safety in Mines Research Establishment; *Applied Ergonomics* 1975 **6** 147–53

The incidence rate for injuries causing more than three days' absence is an imperfect measure of safety performance and its use sometimes causes confusion. A simple model based on the relationship between injury rate and injury severity can help to clarify the situation. Examples of the usefulness of the model are given and some implications of it are discussed briefly.

*Improved methods for the design of winder brake components*
F E Taylor (NCB) and T L Wall *Association of Mining Electrical and Mechanical Engineers Symposium. The Transportation of Men and Materials in Shafts and Underground* 1975 Paper 5b Manchester: Association of Mining Electrical and Mechanical Engineers

Traditional design calculations for mechanical equipment are often based on nominal stresses produced by the static working load increased by a suitable static factor of safety. Some winding engine components undergo fluctuating loads repeated many thousands of cycles per year and hence the mode of failure is more likely to be by fatigue.

Some features of fatigue failure and the factors which influence it are discussed. A comparison is then made of fatigue and static design showing the limitation of the latter for the design of winding engine brake components. Methods of calculation for fatigue design are developed and examples of good design which can help to combat fatigue failure are given. The concept of and necessity for a failure reserve factor is introduced.

Measurement on typical winders has provided a guide to dynamic and secondary stresses.

*Designing and testing safe electrostatic spraying equipment*
P Tolson *Proceedings of the 2nd International Conference on Electrical Safety in Hazardous Atmospheres* (Conference Publication No. 134) 1975 203–07 London: Institution of Electrical Engineers

There are a number of somewhat unusual types of electrical equipment which operate at voltages up to 100 kV but which can be safely used where there are flammable concentrations of dust or vapour. Electrostatic spraying equipment comes into this category and it is unusual because although there are often exposed conductors which are raised to these voltages, discharges to earth are not capable of igniting the flammable atmosphere in which it operates.

BASEEFA have recently brought out a standard for certifying such equipment (SFA 3010) and the Safety in Mines Research Establishment carries out the necessary testing work to ensure that equipment submitted for test complies with the standard. Each piece of equipment has to pass a number of ignition tests which are designed to determine whether or not the equipment can produce discharges which are capable of causing ignition. During the testing of a number of different types of electrostatic paint and powder spraying equipment we have found that it is possible to obtain incendive discharges from the H.T. cable, the insulating barrel of the gun, the nozzle of the gun and even inside passages machined in the gun. We have also found that it is often possible to either eliminate such discharges or to make them harmless by making suitable modifications to the equipment or method of operation.

The mechanisms which give rise to incendive discharges and possible ways of avoiding such discharges are discussed in detail in the paper.

# **Appendix 4** Publications of Research and Laboratory Services Division

The SMRE Bibliography, Safety in Mines Abstracts, SMRE Research Reports and SMRE Reports can be obtained from the Technology Reports Centre, Department of Industry, Orpington, Kent BR5 3RF. Films and SMRE Digests can be obtained from Research and Laboratory Services Division, Health and Safety Executive, Red Hill, Sheffield S3 7HQ.
BASEEFA publications may be obtained from BASEEFA, Health and Safety Executive, Harpur Hill, Buxton, Derbyshire SK17 9JN.
All publications are post-free in the United Kingdom.

### *SMRE Bibliography*

This is a bibliography of the published work of the Safety in Mines Research Establishment and of the Establishment's predecessors. The bibliography covers the period from the foundation of organised research in 1908 to the end of 1968. There are references to over 1700 publications.
325 pages: £1·90.

### *Safety in Mines abstracts*

A wide field of literature, including over 500 periodicals, is searched for material related to SMRE's current interests in health and safety in mines and quarries and the use of electrical equipment in hazardous areas of other industries. A selection of abstracts is published every two months.
Subscription rate (including annual author and subject indexes): available on application.

### *SMRE Research Reports*

277 Experimental coal-dust explosions in the Buxton full-scale surface gallery. IV – The influence of the dust deposit and form of initiation on explosions in a smooth gallery, by D Rae (1972) £0·80

278 Ash and quartz content of respirable airborne dust in a number of British coal mines, by BA Maguire and D Barker (1971) £0·38.

279 Experimental coal-dust explosions in the Buxton full-scale surface gallery. V – A comparison of water-tray and stone-dust barriers, by D Rae (1971) £0·72.

280 Friction tests on wedge-capel materials with various lubricants, by R Jeffrey and VE Taylor (1972) £0·39.

281 An investigation of the gas caps produced by methane in flame lamps, by G Broomhead and SR Howarth (1972) £0·75.

282 Combustion of polyurethane foam in an experimental mine roadway, by DG Wilde (1972) £0·55.

283 Experimental coal-dust explosions in the Buxton full-scale surface gallery. VI – The influence of deposit length, wall roughness and inert content on the rate of development of explosions, by D Rae (1972) £0·51.

284 Experimental coal-dust explosions in the Buxton full-scale surface gallery. VII – An examination of water-trough barriers, by D Rae (1973) £0·68.

### *SMRE Reports*

R1 Proof beyond doubt: the use of 'live' demonstrations in disseminating knowledge, by HR Thompson (1973) £0·59.

R2 A summary of experimental data on the maximum experimental safe gap, by GA Lunn and H Phillips (1974) £0·45.

R3 Mechanical failures: some recent investigations at SMRE, by R Jeffrey and MC White (1976) £1·05.

### *SMRE Technical Papers*

These papers are issued in fairly small numbers and since they are intended primarily for fellow specialists with whom we have publication-exchange arrangements, they are normally supplied free. Individuals and organisations not on our standard circulation lists can apply to RLSD for copies.

P1 The effect of proof loading on the fatigue strength of 1·5% manganese steel short-link chain, by JH Foley (1973).

P2 The SMRE 29-metre tilting wind tunnel, by J McQuaid (1973).

P3 The derivation of confidence limits for the interpretation of incendivity tests on mining explosives, by SP Simpson (1973).

P4 Experience in NCB Doncaster Area with boots fitted with tungsten carbide tipped studs, by CR Senneck and C Nussey (1973).

P5 Measurement of turbulent fluctuating velocities in flows of gas mixtures using a pulsed-wire anemometer, by J McQuaid and W Wright (1974).

P6 Electrical ignition characteristics of hydrogen/oxygen gas mixtures, by FK Pearson and LE Virr (1974).

P7 Experimental coal-dust explosions in the Buxton full-scale surface gallery. VII – Preliminary experiments with flame-triggered self-powered barriers, by D Rae (1974).

P8 The measurement of the volumetric input rate of methane into a methane roof layer, by J McQuaid (1974).

P9 The needs for accident data: what and why? by CR Senneck (1974).

P10 Estimation of forces in a headgear pulley wheel, by TC Corlett (1974).

P11 Progress report on the operation of the SMRE Questionnaire Machine at a small colliery, by TD Proctor (1974).

P12 Propagation of disturbances in granular media, by B Fletcher (1974).

P13 Computer simulation of flame propagation in an open-ended gallery of finite length, by JKW Davies (1974).

P14 Feasibility study of emergency simulation by digital computer, by G Bagshaw (1974).

P15 The effect of blackdamp on the flame of a safety lamp, by G Broomhead and DK Brown (1975).

P16 The use of triple roll mills. An examination of safety and operating aspects, by D Crorkin and SA Matthews (1975).

P17 A theoretical study of the flow of mine-air samples in long tubes, by RD Fitzpatrick (1976).

P18 The economics of compressed air as a power source in hot mines, by J McQuaid (1976).

P19 Optimum cable lengths for intrinsically safe power supplies, by LE Virr (1976).

### *SMRE Digests*

These are very short simple accounts of the results of our work and of the facilities we have available. Single copies are available free.

*Accident Studies*

1 Tungsten carbide tipped studs for anti-slip boots
2 Accident-questionnaire machine
3 Practical experience with miners' boots with tungsten carbide tipped studs

*Electrical hazards*

1 Testing of intrinsically safe electrical equipment
2 Research on flameproof enclosures for electrical equipment
3 On-load testing of flameproof electrical equipment
4 Arc physics
5 Ignition of flammable gases by arc discharges
6 High-voltage equipment for use in flammable atmospheres
7 Testing of types e and N electrical equipment and testing of flameproof electrical equipment

8 Hazards for the volatilisation of insulating materials in flameproof equipment

*Engineering and metallurgy*

1 Large-scale impact machine
2 Strength and energy absorption of wires ropes under impulsive loading
3 Deterioration of wire ropes
4 Metallurgical examination of faulty equipment
5 Fatigue properties of chains
6 Mechanical test facilities
7 Large-scale impact machine – Instrumentation

*Explosions*

1 Combustion of firedamp roof layers
2 The prevention of coal-dust explosions
3 Triggered barriers for the suppression of coal-dust explosions
4 Prevention of explosions in pulverised fuel systems

*Explosives*

1 Ballistic-pendulum and ballistic-mortar tests for coalmining explosives
2 Cannon test for coalmining explosives
3 Ignition of firedamp by coalmining explosives
4 Break tests for P4 and P5 coalmining explosives
5 Explosives in coal mines

*Fires*

1 Fires in rigid polyurethane foam
2 Withdrawn
3 Withdrawn
4 Smoke and fumes from mine fires
5 Ignition and burning of pools of mineral hydraulic oil – some early results of an experimental study
6 Behaviour of high-expansion foam in storage tanks

*Frictional ignitions*

1 Firedamp ignition hazard from coal and rock-cutting machines
2 Frictional ignition tests on boot studs
3 Firedamp ignition hazards from light alloys
4 Firedamp ignition by hot surfaces produced by impact and friction
5 The ignition hazard from glass

*Gas detection*

1 Use of a metallised membrane electrode in the monitoring of oxygen, carbon monoxide and other gases
2 Catalytic oxygen-deficiency detector
3 Infrared hydrocarbon detector
4 Fluorescence-quenching oxygen monitor
5 A non-ambiguous catalytic detector for methane
6 Gas detection with semiconductor metal oxides
7 Circuitry techniques in a catalytic carbon-monoxide detector
8 Circuitry techniques in a flashing methane alarm
9 Circuitry techniques in a combustible-gas alarm
10 The oxygen-deficiency hazard and its detection
11 Gas detection with catalytic elements
12 Withdrawn

*General*

1 The work of the Safety in Mines Research Establishment
2 SMRE exhibitions programme
3 16-mm cine films (sound)

*Incident investigation*

1 Use of small-scale models in the investigation of mine explosions

*Respirable dust*

1 SIMPEDS 70 Mk 2: a personal gravimetric respirable dust sampling instrument
2 SIMSLIN: a respirable dust sampling instrument using a light-scattering method
3 The SMRE dust helmet
4 SIMSTADS: a lightweight gravimetric respirable dust sampling instrument
5 SIMQUADS: a personal gravimetric respirable dust sampler for use in non-mining situations

*Respiratory apparatus*

1 Breathing resistance of respiratory apparatus
2 Liquid-oxygen breathing apparatus
3 Self-rescuers
4 Inhalation of carbon dioxide

*Special projects*

1 Rock-cutting and fragmentation by water jets
2 An aspect of nuclear reactor safety

### *16-mm Colour Sound Films*

Foam plug: preliminary research into a new method of fighting mine fires, 18 min 1956
Firedamp roof layers, 25 min 1960
Stone-dust barriers, 17 min 1962
Testing for roof layers with the flame lamp, 30 min 1967
The assessment of fire hazards in mines, 10 min 1969
A history of the health and safety of the miner, 55 min 1970
SMRE oxygen deficiency monitors, 12 min 1971
The behaviour of airborne dust, 10 min 1974
Flixborough – a record of SMRE investigations, 10 min 1974

*16-mm colour sound film (lecture support material)*

Flameproof electrical apparatus, 6½ min 1970

These films can either be purchased or obtained on loan; details are available from RLSD

### *BASEEFA Certification Standards*

| | | |
|---|---|---|
| SFA 3002 | Petrol metering pumps | £1·00. |
| SFA 3004 | Shunt diode safety barriers | £2·00. |
| SFA 3006 | Battery operated vehicles | £1·00. |
| SFA 3007 | Instruments for measuring gas concentration | £1·00. |
| SFA 3009 | Special protection | £1·00. |
| SFA 3010 | Electrostatic paint and powder spray guns | £2·00. |
| SFA 3012 | Intrinsic Safety | £1·50. |
| SFA 3013 | Oil immersed apparatus | £1·00. |

### *Ex Memo No. 1*

Explanatory memorandum on labelling of certified equipment £0·50.

### *Technical Abstracts*

| | |
|---|---|
| No. 1–65 | £0·25. |
| No. 66–118 | £0·25. |
| No. 119–222 | £0·50. |

### *List of Certified Electrical Equipment*

Fourth edition (to 31 December 1973) £1·00.

### *PTB Testing Memorandum*

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